OCTOBER 31, 1961

WATER & SEWAGE WORKS

ERENCE NUMBER

Water & Sewage Works Presents It's 1961 Reference Number

For the 28th time
Water & Sewage Works is
publishing a Reference Number.

This 1961 Reference Number
is issued with the hope of the
publisher and the editor that it will
be a useful text and information work in this field.

This Reference Number,
like its predecessors, is a reference
book or "manual" in the field of water sup-
ply and sewage disposal; it is a manual which
is revised and updated each year with the most im-
portant technical matter published during the previous year.

Each Reference Number
is, therefore, a single place to
find the best and latest material on the
field covered, for current and future reference.

Many technical articles
do not become outdated for several years,
and, therefore, subscribers should retain at least the
past four Numbers in order to have a complete "library".
To aid the reader, each Number contains a consolidated index
covering the past four issues as well as the current issue. For
the benefit of new subscribers, this issue contains some basic material
charts, and data, used in previous issues.

All subscribers
to Water & Sewage Works receive
the Reference Number without extra charge.

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WATER & SEWAGE WORKS

REFERENCE NUMBER

OCTOBER 31, 1961

PUBLISHER—E. Scranton Gillette
EDITOR—V. W. Langworthy
ASSISTANT EDITOR—C. Terrazas
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PUBLISHED BY SCRANTON PUBLISHING CO., INC.
CHICAGO OFFICE—185 N. WABASH AVE., CHICAGO
NEW YORK OFFICE—155 EAST 44 ST., NEW YORK
PITTSBURGH OFFICE—239 FOURTH AVE., PITTSBURGH, PA.

WATER & SEWAGE WORKS is published monthly with an extra issue in Oct. Subscriptions including the Reference Number in the U. S. and Canada, 1 year $5.00; 2 years $7.50; 3 years $10.00. Other countries $1.50 per year additional. Single copies 50c except Reference Number $1.00.

WATER & SEWAGE WORKS, Reg. U. S. Patent Off. Published monthly by Scranton Publishing Co., at Pontiac, Ill. Entered as second class matter at the post office at Pontiac, Ill., under Act of March 3, 1879.

MEMBER OF THE AUDIT BUREAU OF CIRCULATION AND ASSOCIATED BUSINESS PUBLICATIONS, INC.

INTRODUCTION

This, the twenty-eighth issue of WATER & SEWAGE WORKS' Reference Number, again gives your editors the opportunity to comment on the acceptability and durability of this annual effort. This year's issue contains a compilation of papers selected from recent WATER & SEWAGE WORKS issues, plus new manuscripts obtained specifically for this issue. In the latter category is a group of papers on coagulation and sedimentation. These were presented by the authors at an in-service training course held at the University of Michigan in February, 1961, and are published herein with the permission of the sponsors.

No substantial changes have been made in the Reference Number format from previous years. Our readers have become familiar with organization of the text, and we prefer to retain the overall similarity from issue to issue. It should be noted, however, that the broad nature of this industry precludes development of new information annually in each category of interest. Where a specific subject is not included in this issue, readers are, therefore referred to the index where references to four previous Reference Numbers will be found. In most cases, the best and most recent treatment of the subject can be located in this manner.

Substantial and significant developments have occurred since the last Reference Number went to press. High level conferences have been held at which water pollution, ground water supplies and instrumentation have been thoroughly discussed. The Senate Select Committee on National Water Resources has rendered its report, and federal legislation relating to pollution abatement has been greatly strengthened and expanded. Both national associations, AWWA and WPCF, have been strengthened. WPCF has adopted its "Statement on Water Pollution Control" and AWWA has accepted a tremendous report from its Aims and Objectives Committee. Also, AWWA retained a management consultant to study its organization and operation. The Water and Sewage Works Manufacturers Association is continuing the public information program and can point to many hours of radio and television time, as well as many column inches of press space, as a result of National Water Institute efforts.

Perhaps the year's most popular subject, of interest to this industry, has been progress in the Office of Saline Water's demonstration plant program. Much publicity was generated by the start-up of the first demonstration plant at Freeport, Texas. Similar informational programs should accompany starting of the remaining plants. Increased funds are expected to be made available to the OSW in order to construct additional demonstration plants and, perhaps more important, to conduct basic research to evolve separation techniques not now known. In the meantime, though, operating reports and other information should be available from the demonstration plants so that technicians everywhere can be aware of both success and failure.

The need continues for research in other areas and part of this need is being met by grants available from the U. S. Public Health Service. WATER & SEWAGE WORKS has in the last year been most fortunate in being able to publish Research Progress Reports prepared by many investigators working in this grant program. It is hoped that authors will continue to submit reports of their research progress as situations permit. The revised and expanded legislation relating to water pollution control provides for research. If money is appropriated for this purpose, continued increases in research activities should clarify our understanding of fundamental water resource problems. Ultimately applications should follow which will provide water and wastewater technicians with problem solving procedures and devices.

Functional Operations

Water and wastewater subjects are included, dealing with metering, pumping and telemetering. Instrumentation continues to be incorporated into plant and system designs to do better automatically those operations which formerly were manually performed. Attention to quality control for pipeline protection and a method for corrosion measurement are provided.

Water Works Operations

National publicity has accompanied the desalting demonstration plant program. A rational view of the situation has been included here, which emphasizes a common sense and realistic approach to the economies involved.

The presence of synthetic detergents in ground and surface water has received much attention. Removal methods are being studied and, for the first time, a standard limiting syndet concentration has been set for water furnished to interstate carriers.

Information has been consolidated for butterfly valve operator selection, vertical pumps, pump materials and hypochlorite feeding equipment. While national interest in municipal water fluoridation has tapered off, valuable data are reported on costs incurred at existing installations.

Progress in the construction of new water softening plants continues, but at a slow pace. Data have been accumulated which reveal the economy of central softening, even

though synthetic detergents may be in popular use. Split treatment as a means of restoring bicarbonate alkalinity to lime-soda softened water has received attention. A complete treatment of coagulation and sedimentation, not previously published, bring an up-to-date reference in this important field.

Sewage Works Operations

Much research is being conducted aimed at means for detecting stream pollution. Means sought include biological and chemical, plus instrumentation of existing and new techniques.

Considerable impetus has been given to use of waste stabilization lagoons for municipalities, and studies aimed at increasing our understanding of principles involved are in progress. Tertiary treatment methods are under development, but applicable techniques have not as yet become readily available. It should be noted, however, that considerable work is being directed toward increased utilization of algae.

Ocean disposal, where possible, is being made increasingly efficient as a result of wind, current and diffusion studies now available.

Design and Construction

Typical examples of treatment plant conception and design execution have been selected for reference purposes. Some present unique twists to old ideas, others involve some new concepts. Designs are bound to incorporate fresh approaches as increasingly stringent demands are placed on the technician to improve product quality.

Technical Data

Some new devices have been prepared and included in this issue in addition to the regular indispensable information. A critical comparison of the multi-tube dilution and membrane filter methods for coliform enumeration in marginal waters has been made available. Also, one example of research aimed at developing a suitable detecting medium for the membrane filter is included.

Product Directory and Purchasing Guide

The publisher has included a completely reorganized bulletin and catalogue reference system in this issue. The section is alphabetically organized on an equipment application basis, which is designed to simplify selection of appropriate literature.

V. W. Langworthy

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and

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Department of Health
Ponce de Leon Bldg.
San Juan 18, Puerto Rico

Rhode Island
Jeremiah A. Dailey
Director of Health
Department of Health
State Office Bldg.
Providence 3, Rhode Island

So. Carolina
W. T. Linton, Executive Director
State Water Poll. Control Auth.
Rm. 417 Wade Hampton Bldg.
Columbia 1, South Carolina

So. Dakota
Charles E. Carl
Secretary & Executive Officer
Committee on Water Pollution
State Capitol
Pierre, South Dakota

Tennessee
S. Leary Jones, Director
Stream Pollution Control Board
Cordell Hull Bldg.
Sixth Ave. North
Nashville 3, Tennessee

Texas
David F. Smallhorst
Director, Div. of Water
Pollution Control
State Dept. of Health
1100 W. 49th St.
Austin 5, Texas

Utah
Lynn M. Thatcher, Exec. Secy.
Water Poll. Cont. Board
45 S. Ft. Douglas Blvd.
Salt Lake City 13, Utah

Vermont
R. W. Thieme, Commissioner
State Water Conservation Board
State Off. Bldg.
Montpelier, Vermont

Virginia
A. H. Paessler, Executive Secy.
State Water Control Board
415 W. Franklin Street
Richmond 20, Virginia

Virgin Islands
Dr. Melvin H. Evans
Commissioner of Health
Virgin Islands Department
of Health
Charlotte Amalie, St. Thomas
Virgin Islands

Washington
Art Garton, Director
Staate Poll. Control Commission
Old Capitol Bldg.
Olympia, Washington

W. Virginia
Bern Wright, Exec. Secy.
State Water Commission
Charleston 1, West Virginia

Wisconsin
Theodore F. Wisniewski, Dir.
Committee on Water Pollution
State Office Building
Madison 2, Wisconsin

Wyoming
H. W. Kassel, M. D.
Act. Dir. of Public Health
State Dept. of Public Health
State Off. Bldg.
Cheyenne, Wyoming

Interstate Agencies

Bi-State Agency
Lief J. Sverdrup, Chairman
Bi-State Development Agency
915 Olive Street
St. Louis 1, Missouri

Delaware River
James H. Allen, Exec. Secretary
Interstate Commission on
the Delaware River Basin
Suburban State Bldg.
Philadelphia 3, Pennsylvania

New England
Joseph C. Knox, Secretary
New England Interstate Water
Pollution Control Comm.
73 Tremont Street
Boston 8, Massachusetts

Klamath River Compact Comm.
R. R. Bond, Exec. Secy.
P. O. Box 388
Sacramento 5, Calif.

N. Y., N. J., Conn.
Thos. R. Glenn, Jr.
Director and Ch. Engr.
Interstate Sanitation Comm.
10 Columbus Circle
New York 19, New York

Ohio River
Edward J. Cleary
Exec. Dir. & Ch. Engr.
Ohio River Valley Water
Sanitation Comm.
414 Walnut Street
Cincinnati 2, Ohio

Interstate Comm. on the Potomac River Basin
Ellis S. Tisdale, Director
The Potomac River Basin
203 Transportation Bldg.
815 - 17th St., N. W.
Washington 6, D. C.

Books and Reference Manuals

Suggested Library Material for Water and Sewage Works

Title and Price (F=Free)	*Publisher*	*Author*
I. Books for All Water and Sewage Works		
Book of pH ($6.00)	*The* Macmillan Co.	Weber
First Aid, Surgical and Medical 4th Ed. ($4.00)	Appleton-Century-Crofts, Inc.	Cole and Puestow
Glossary—Water and Sewage Control Engineering ($2.00)	ASCE, APHA, AWWA, WPCF	
Handbook of Cast Iron Pipe, 2nd Ed.	Cast Iron Pipe Research Assn.	
Industrial Waste Treatment, Principles of	John Wiley & Sons	Gurnham
Laboratory Manual for Chemical & Bacterial Analysis of Water and Sewage 3rd Ed. ($5.00)	McGraw-Hill Book Co.	Theroux, Mallmann & Eldridge
Lime Handling, Application and Storage in Treatment Processes (F)	National Lime Assn.	Rudolfs
Modern pH and Chlorine Control, 14th Ed. (F)	W. A. Taylor Co.	Taylor & McCrumb
Pipe Friction Manual, 1954 Ed. ($1.75)	Hydraulic Institute	
Rural Water Supply and Sanitation, 2nd Ed. ($4.90)	John Wiley & Sons	Wright
Standard Methods for the Examination of Water, Sewage, and Industrial Wastes, 11th Ed. ($7.50)	APHA, AWWA, & WPCF	
Water Conditioning Data Book, 4th Ed. (F)	The Permutit Co.	
Water for Industry ($3.75)	Am. Assn. for Advance of Science	Graham, Burrill, et al
II. Books for Large Water and Sewage Works		
Aspects of River Pollution ($14.50)	Academic Press, Inc.	Klein
Chemistry for Sanitary Engineers	McGraw-Hill Book Co.	Sawyer
Civil Engineering Handbook, 4th Ed. ($17.50)	McGraw-Hill Book Co.	Urquhardt
Corrosion: Causes and Prevention, 3rd Ed. ($12.00)	McGraw-Hill Book Co.	Speller
Corrosion Handbook ($16.00)	John Wiley & Sons	Uhlig
Data Book for Civil Engineers, I—Design, 2nd Ed. ($16.75)	John Wiley & Sons	Seelye
Data Book for Civil Engineers, II—Specifications and Costs, 3rd Ed. ($20.00)	John Wiley & Sons	Seelye
Data Book for Civil Engineers, III—Field Practice, 2nd Ed. ($7.50)	John Wiley & Sons	Seelye
Dictionary of Mechanical Engineering ($6.00)	Philosophical Library, Inc.	Del Vecchio
Elementary Theoretical Fluid Mechanics ($7.50)	John Wiley & Sons	Brenkert
Elements of Water Supply and Waste-Water Disposal ($8.95)	John Wiley & Sons	Fair & Geyer
Engineering in Public Health ($9.50)	McGraw-Hill Book Co.	Babbitt
Flow Measurement and Control ($11.00)	*The* Macmillan Co.	Coxon
Flow Meter Engineering Handbook ($7.50)	Minneapolis-Honeywell Co.	Cusick
Freshwater Biology, 1918 Ed. ($12.00)	John Wiley & Sons	Ward & Whipple
Fundamental Considerations in Rates and Rate Structures for Water and Sewage Works—Joint Comm. Rept. ($0.75)	ASCE, ABA, AWWA, APWA, NARUC, MFOA, IBAA, WPCF	
Handbook of Aplied Hydraulics, 2nd Ed. ($17.50)	McGraw-Hill Book Co.	Davis
Handbook of Chemistry and Physics, 40th Ed. ($12.00)	Chemical Rubber Co.	
Handbook of Chemistry, 9th Ed. ($12.00)	McGraw-Hill Book Co.	Lange
Handbook of Hydraulics, 5th Ed. ($10.00)	McGraw-Hill Book Co.	King
Handbook of Microbiology ($8.50)	D. VanNostrand Co., Inc.	Jacobs & Gerstein
Hydraulic Tables, 3rd Ed. ($4.50)	John Wiley & Sons	Williams & Hazen
Industrial Water & Industrial Waste Water, Continuous Analysis of, S.T.P. 130 1953 Ed. ($1.50)	Am. Soc. Test. Mtls.	
Introduction to the Bacteria, 2nd Ed. ($7.50)	McGraw-Hill Book Co.	Clifton
Mechanical Engineers' Handbook, Power Volume, 12th Ed. ($10.00)	John Wiley & Sons	Kent-Salisbury
Microbiology, 2nd Ed. ($7.50)	Appleton-Century-Crofts, Inc.	Kelly & Hite
Pipe Friction Manual—1954 Ed. ($1.75)	Hydraulic Institute	
Plane Surveying ($6.75)	John Wiley & Sons	Tracy
Practice of Sanitation ($8.00)	Williams & Wilkens Co.	Hopkins & Schulze
Public Health Engineering, Vol. I ($8.50)	John Wiley & Sons	Phelps
Public Health Engineering, Vol. II ($5.50)	John Wiley & Sons	Phelps
Pump Handbook ($4.00)	*The* National Press	Finch
Pumps ($6.50)	McGraw-Hill Book Co.	Kristal & Annett
Rainfall and Runoff ($10.00)	*The* Macmillan Co.	Foster
Rosenau Preventive Medicine and Public Health	Apleton-Century-Crofts, Inc.	Maxcy
Specifications and Law on Engineering Works ($6.50)	John Wiley & Sons	Sadler
Standards of the Hydraulic Institute, 10th Ed. ($4.75)	Hydraulic Institute	
Standard Mathematical Tables, 10th Ed. ($3.00)	Chemical Rubber Co.	

Title and Price (F=Free)	*Publisher*	*Author*
Standard Practices for Low and Medium Speed Stationary Diesel Engines, 4th Ed. ($5.00)	Diesel Engine Mfrs. Assn.	
Theory, Design and Operation of the Rated Aeration Waste-Water Treatment Process	Chicago Pump	Engineering-Science, Inc.
Water Supply and Waste-Water Disposal ($16.00)	John Wiley & Sons	Fair & Geyer
Zinsser's Bacteriology, 11th Ed. (1951) ($12.00)	Smith & Conont	

III. Books for Small and Large Water Works

Fluoridation as a Public Health Measure ($4.50)	Am. Assn. for Advance of Science	Shaw, et al
Legal Guide for Water Works Men ($1.00)	R. H. Donnelley Co.	
Manual for Water Plant Operators ($6.50)	Chemical Publishing Co.	Hirsch
Manual for Water Works Operators, 3rd Ed. ($5.00)	Tex. Wat. & Sew. Wks. Assn.	Billings, et al
Operation of Water Filtration Plants of Mechanical Gravity Type—Bul. No. 484 ($1.00)	San. Eng. Div., No. Car. St. Board of Health	
Taste and Odor Control in Water Purification, 2nd Ed. (F)	Industrial Chemical Sales Div., W. Va. Pulp & Paper Co.	
Water Supply and Treatment, 8th Ed. ($2.00)	National Lime Assn.	Hoover-Riehl
Water Works Operation ($1.00)	R. H. Donnelley Co.	
Water Works Questions and Answers ($1.00)	R. H. Donnelley Co.	

IV. Books for Small and Large Sewage Works

Compressed Air Handbook, 2nd Ed. $8.00)	McGraw-Hill Book Co.	
Control of Sludge Quality ($1.00)	R. H. Donnelley Co.	
Controlling Roots in Sewers, Spec. Rept. No. 5 ($1.00)	APWA	
Handbook of Cast Iron Pipe, 2nd Ed. (F)	Cast Iron Pipe Research Assn.	
Laboratory Control of Sewage Treatment ($1.00)	R. H. Donnelley Co.	
Manual for Sewage Plant Operations, 2nd Ed. ($6.50)	Tex. Wat. & Sew. Wks. Assn.	Billings, et al
Manuals of Practice (1-9)	WPCF	
Practice of Sanitation ($8.00)	Williams & Wilkins	Hopkins & Schulze
Principles of Sewage Treatment, 4th Ed. ($1.25)	National Lime Assn.	Rudolfs
Recent Developments in Chlorination Practice, Spec. Rept. No. 9 ($1.00)	APWA	
Sewage Treatment, 2nd Ed. ($7.50)	John Wiley & Sons	Imhoff & Fair
Sewage Works Guide ($1.00)	R. H. Donnelley Co.	

V. Books for Large Water Works

Fresh Water Algæ of the U. S., 2nd Ed. ($13.00)	McGraw-Hill Book Co.	Smith
Ground Water ($10.00)	McGraw-Hill Book Co.	Tolman
Hydroelectric Handbook, 2nd Ed. ($17.00)	John Wiley & Sons	Creager & Justin
Hydrology, 2nd Ed. ($7.50)	John Wiley & Sons	Wisler & Brater
Index to Journal AWWA—1940-55 ($4.50)	AWWA	
Ion Exchange Resins, 2nd Ed. ($11.00)	John Wiley & Sons	Kunin
Laboratory Control of Water Purification ($4.00)	R. H. Donnelley Co.	C. R. Cox
Manual of Water Works Accounting ($4.00)	AWWA	
Manual on Industrial Water, 1957 Ed. ($7.50)	ASTM	
Microscopy of Drinking Water, 4th Ed. ($12.00)	John Wiley & Sons	Whipple, Fair & Whipple
NFPA Handbook of Fire Protection, 11th Ed. ($10.50)	National Fire Protection Assn.	
Physics of Flow Through Porous Media ($14.00)	*The* Macmillan Co.	Scheidegger
Public Water Supplies, 4th Ed. ($7.75)	John Wiley & Sons	Turneaure & Russell
Survival and Retirement Experience with Water Works Facilities ($3.00)	AWWA	
The Quest for Pure Water ($5.00)	AWWA	N. M. Baker
Water Bacteriology, 6th Ed. ($5.25)	John Wiley & Sons	Prescott, Winslow & McCrady
Water Conditioning for Industry ($10.00)	McGraw-Hill Book Co.	Powell
Water Power Engineering, 2nd Ed. ($10.00)	*The* Macmillan Co.	Hammond
Water Quality and Treatment, 2nd Ed. ($5.00)	AWWA	
Water Supply ($7.50)	The Univ. of Chicago Press	Hirshleifer, DeHaven & Milliman
Water Supply and Waste Disposal ($11.00)	International Textbook Co.	Hardenbergh and Rodie
Water Supply Engineering, 5th Ed. ($8.75)	McGraw-Hill Book Co.	Babbitt & Doland
Water Supply and Sewerage, 4th Ed. ($11.00)	McGraw-Hill Book Co.	Steel
Water Treatment for Industrial and Other Uses ($12.00)	Reinhold Book Division	Nordell

VI. Books for Large Sewage Works

American Sewage Practice—Vol. III—Disposal of Sewage, 3rd Ed. ($10.00)	McGraw-Hill Book Co.	Metcalf & Eddy
Biological Treatment of Sewage and Industrial Waste— Vol. I—Aerobic Oxidation ($10.00) Vol. II—Anaerobic Digestion ($11.00)	Reinhold Book Div.	McCabe & Eckenfelder

Title and Price (F=Free)	*Publisher*	*Author*
Disposal of Industrial Wastes Materials ($7.50)	*The* Macmillan Co.	So. Chem. Industry
Disposal of Radioactive Wastes ($3.50)	*The* Macmillan Co.	Saddington & Templeton
Index, Sewage Works Journal (1928-48) ($4.50)	WPCF	Wisely & Symons
Index, Sewage & Industrial Wastes (1949-58)	WPCF	
Industrial Waste Disposal Charges in Cities over 5000 Population, Spec. Rept. No. 18-S ($2.00)	APWA	Baffa, et al
Industrial Wastes, Their Treatment and Disposal ($9.50)	Reinhold Book Div.	Rudolfs, et al
Industrial Waste Treatment ($7.00)	McGraw-Hill Book Co.	Besselievre
Industrial Waste Treatment, Principles of	John Wiley & Sons	Gurnham
National Plumbing Code	U. S. Gov't Printing Office	
Recommended Minimum Requirements for Plumbing ($1.25)	Am. Soc. Mech. Engrs. ASA-A-40.8-1955	
Sewage Service Charges in Cities over 5000 Population Spec. Rept. No. 18 ($2.00)	APWA	Tatlock, et al
Sewage Treatment ($5.50)	Butterworth, Inc.	Bolton & Klein
Sewerage and Sewage Disposal, 2nd Ed. ($12.00)	McGraw-Hill Book Co.	Metcalf & Eddy
Sewerage and Sewage Treatment, 3rd Ed. ($6.75)	International Textbook Co.	Hardenbergh
Sewerage and Sewage Treatment, 7th Ed. ($8.75)	John Wiley & Sons	Babbitt
Stream Sanitation ($6.00)	John Wiley & Sons	Phelps
Uniform System of Accounts for Sewer Utilities ($5.00)	WPCF	

VII. Technical Reports, Manuals, Bulletins and Reprints[1]

A. Useful in Both Water and Sewage Works

Animals Associated with Potable Water Supplies	AWWA	Ingram & Bartsch
Chemical Lime Facts (F)	National Lime Assn.	
Concrete Pipe Field Manual	Am. Concrete Pipe Assoc.	Peckworth
Concrete Pipe for Irrigation and Drainage	Am. Concrete Pipe Assoc.	Peckworth
Concrete Pipe Handbook	Am. Concrete Pipe Assoc.	Peckworth
Conversion Factors for Engineers, 23rd Ed. (F)	Dorr-Oliver, Inc.	
Financing Water Works and Sewerage Works Projects ($2.00)	Mo. Wat. & Sew. Conf.	Summers
Flow of Fluids Through Valves, Fittings and Pipe, 1956 Ed. (F)	Crane Co.	
Flow of Water in Cast Iron Pipe (F)	Cast Iron Pipe Research Assn.	
Keep Sheets of B-I-F Industries, Inc. ($1.00)	B-I-F Industries, Inc.	
Manual on Chemical Feed Machines, 1953 Ed. ($2.00)	Mo. Wat. & Sew. Conf.	Schworm
Manual on Consumer Water Rates, Part I, 1952 Ed. ($2.00)	Mo. Wat. & Sew. Conf.	Miller
Chlorination Guide ($0.60)	*The* Chlorine Institute	Laubusch
Hypochlorination Guide ($0.40)	*The* Chlorine Institute	Laubusch
Public Relations Manual for Water Works and Sewage Works Operators ($2.00)	Mo. Wat. & Sew. Conf.	Magill
Safety Manual ($1.50)	AWWA	
Specifications for Stationary Chlorine Storage Installations ($0.10)	*The* Chlorine Institute	
The Chlorine Manual ($0.50)	*The* Chlorine Institute	

B. Useful in Water Works

Algæ in Water Supplies ($1.00)	U. S. Gov't Printing Office	Palmer
Basic Water Works Manual	Am. Concrete Pipe Assoc.	Sweitzer
Community Relations Portfolio	Cast Iron Pipe Res. Assn.	
Copper Sulfate in Control of Microscopic Organisms, 1954 Ed. (F)	Phelps Dodge Refining Corp.	Hale
Drinking Water Standards ($0.10)	U. S. Gov't Printing Office	
Fire Engine Tests and Fire Stream Tables (F)	Nat. Bd. Fire Underwriters	
Hydraulics of Culverts	Am. Concrete Pipe Assoc.	Hendrickson
Management Manual ($2.00)	AWWA	
Manual of Instruction for Water Treatment Plant Operators ($1.00)	N. Y. State Dept. of Health	
Operation and Repair of Water Facilities in Civil Defense Emergencies ($0.25)	U. S. Gov't Printing Office	
Pamphlets on Story of Water ($0.05 to $0.10)	AWWA	
Priceless Water Is Your Business (F)	Johns-Manville Corp.	
Reprints of AWWA Committee Reports and Standards (order by number from list of AWWA publications)	AWWA	
Silent Service Is Not Enough—Public Relations ($1.50)	AWWA	
Water, Make Sure You'll Have Plenty (F)	Cast Iron Pipe Res. Assn.	
Water Rates Manual ($1.25)	AWWA	
Water Rate Structures in America—1940 Ed. ($0.25)	Pub. Serv. Comm. of Wis.	
What Price Water ($0.10)	AWWA	

(1) The U. S. Public Health Service, all State Health Departments, the AWWA, WPCF, and most colleges of engineering have many manuals, bulletins, and reprints (at nominal prices) of interest to water and sewage plant operation. Also, equipment manufacturers offer free technical reprints on equipment and process operation in the fields of water supply and sewage disposal.

Title and Price (F=Free)	*Publisher*	*Author*

C. USEFUL IN SEWAGE WORKS

Copper Sulfate for Root and Fungus Control in Sanitary Sewers and Storm Drains, 1954 Ed. (F)	Phelps Dodge Refining Corp.	Hood
Engineering Solutions to Industrial Wastes Treatment Problems ($1.00)	R. H. Donnelley Co.	
Engineering Solutions to Sewage Treatment Plant Design Problems ($1.00)	R. H. Donnelley Co.	
Filtering Materials for Sewage Treatment Plants	ASCE	
How to Get Top Performance from Sewage Treatment Plants ($1.00)	R. H. Donnelley Co.	
Manual of Instruction for Sewage Treatment Plant Operators ($1.00)	N. Y. State Dept. of Health	
Manuals of Practice Nos. 1, 2, 3, 4, 5, 6 (various prices)	WPCF	
Report of Committee of Great Lakes—Upper Mississippi River Board of State Sanitary Engineers—Bull. No. 42 ($1.00)	N. Y. State Health Dept.	
Sewage Treatment Plant Design ($7.00)	WPCF	
Uniform System of Accounts for Sewer Utilities ($5.00)	WPCF	

Addresses of Technical Book Publishers

Academic Press, Inc.	111 Fifth Avenue, N. Y. 3, N. Y.
American Association for the Advancement of Science	1025 Connecticut Ave., N. W., Washington 6, D. C.
American Concrete Pipe Assn.	228 N. La Salle St., Chicago, Ill.
American Public Works Assn.	1313 East 60th St., Chicago 37, Ill.
American Society for Testing Materials	1916 Race St., Philadelphia 3, Pa.
American Society of Civil Enginers	33 West 39th St., New York, N. Y.
American Water Works Assn.	2 Park Ave., New York 16, N. Y.
Appleton-Century-Crofts, Inc.	35 West 32nd St., New York 1, N. Y.
B-I-F Industries, Inc.	345 Harris Ave., Providence, R. I.
Butterworth, Inc.	7235 Wisconsin Ave., Washington 14, D. C.
Cast Iron Pipe Research Assn.	Suite 3440, Prudential Plaza, Chicago 1, Ill.
Chemical Publishing Co., Inc.	212 Fifth Ave., New York 10, N. Y.
Chicago Pump Co.	622 Diversey Parkway, Chicago 14, Ill.
Crane Co.	836 S. Michigan Ave., Chicago 5, Ill.
Diesel Engine Manufacturers Assn.	1 N. La Salle St., Chicago 2, Ill.
F. W. Dodge Corporation	119 W. 40th St., New York 18, N. Y.
R. H. Donnelley Co.	466 Lexington Ave., New York 17, N. Y.
Dorr-Oliver, Inc.	Stamford, Conn.
Hydraulic Institute	122 E. 42nd St., New York 17, N. Y.
Industrial Chemical Sales Div., West Virginia Pulp & Paper Co.	230 Park Ave., New York 17, N. Y.
International Text Book Co.	Scranton 15, Pa.
Johns-Manville Corp.	22 E. 40th St., New York 16, N. Y.
John Wiley & Sons, Inc.	440 Fourth Ave., New York 16, N. Y.
McGraw-Hill Book Co.	330 West 42nd St., New York 36, N. Y.
Minneapolis-Honeywell Regulator Co.	Wayne and Windrim Avenues, Philadelphia 44, Pa.
Missouri Water and Sewerage Conference	State Office Bldg., Jefferson City, Mo.
National Board of Fire Underwriters	85 John St., New York 38, N. Y.
National Fire Protection Assn.	60 Batterymarch St., Boston 10, Mass.
National Lime Assn.	925 Fifteenth St., N. W., Washington 5, D. C.
New York State Dept. of Health	Albany, N. Y.
North Carolina State Health Dept.	Raleigh, N. C.
Phelps Dodge Refining Corp.	300 Park Ave., New York 22, N. Y.
Philosophical Library, Inc.	15 E. 40th St., New York 16, N. Y.
Public Service Commission of Wisconsin	State Office Bldg., Madison, Wis.
Reinhold Book Division	430 Park Ave., New York 22, N. Y.
Texas Water and Sewage Works Assn.	1100 West 49th St., Austin, Tex.
The Chemical Rubber Co.	2310 Superior Ave., Cleveland 14, Ohio
The Chlorine Institute	342 Madison Ave., New York 17, N. Y.
The Macmillan Co.	60 Fifth Ave., New York 11, N. Y.
The National Press	850 Hansen Way, Palo Alto, Calif.
The Permutit Co.	50 West 4th St., New York 36, N. Y.
United States Gov't Printing Office	Washington 25, D. C.
University of Chicago Press	Chicago 37, Illinois
Van Nostrand Co., Inc.	120 Alexander St., Princeton, N. J.
Water Pollution Control Federation	4435 Wisconsin Ave., N. W., Washington 16, D. C.
W. A. Taylor & Co.	7300 York Road, Baltimore 4, Md.
Williams & Wilkins Co.	428 E. Preston St., Baltimore 2, Md.

Cities Can and Must Provide Municipal Waste Treatment *Not* Sewage Treatment Only

by JOHN E. KINNEY
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■ ANY NATIONWIDE IMPROVEMENT program born of great urgency to overcome the errors of past practice is in danger of developing shortsighted means of accomplishment. To get things going, a program of expediency rather than of long-range vision may be adopted. This is true of our pollution control program.

Pollution control has been divided into sewage treatment and industrial waste treatment. The division has been one of convenience. It was devised originally as a means of providing separate bases for administration of laws and for characterization of wastes. The separation has now become a hurdle in any effort to obtain recognition of the need for cities to provide facilities for treatment of all liquid wastes, whether originating in a dwelling or an industry.

Sewage treatment originated as a public health measure to reduce spread of disease. Further studies indicated that the solids in sewage had a depleting effect on the dissolved oxygen in the receiving stream. So facilities were developed to provide varying degrees of removal of the solids with an accompanying reduction in the material that would reduce the oxygen in the river. The relationships between the methods of treatment, solids removed, and reduction in oxygen-consuming material were defined.

From that time on, the fundamental purpose of sewage treatment was forgotten. Instead of protection of the stream, the criteria of design became the objectives of design. Municipalities receive orders to design primary, intermediate or complete treatment plants, wherein the terms are defined in percentage reduction of solids and oxygen-consuming material. "Complete" treatment indicates 85 per cent reduction in oxygen-consuming material and substantially complete removal of settleable solids. No thought is given to the effects of the residual material on stream uses.

In a municipality, the sewers were designed to separate storm and "sanitary sewage" the greatest misnomer of all time, without specifying there could be no industrial connections. Such connections were considered normal.

In time, the effects of some industrial discharges on the sewers and on the treatment plant became evident. The reaction was to promote prohibitions on the discharge of industrial wastes to municipal sewers. The criteria for acceptance of industrial waste were solids and BOD, the measure of oxygen-consuming material. The objectives for design of the municipal plant became the basis for acceptance to the sewers. Industrial waste was compared to a figment of the imagination called "normal sewage".

A city sewage treatment plant then is designed to remove an average percentage of solids, reduce an average percentage of oxygen-consuming material and provide for varying degrees in reduction of the number of bacteria of human origin. The average percentage reduction is determined by analysis of influent and effluent to the treatment plant. These data do not indicate the volume of raw sewage that bypasses the plant, either at the plant or at diversion manholes along the intercepting sewers. The bypassing is excused with the argument that it is not economically feasible to provide facilities to treat all of the flow. Alternative methods of reducing the seriousness of this bypassing are not considered.

Industrial Connections

This same logic is not applied by the cities to industrial discharges to its sewers. The city argues it cannot protect the river at all times, but the industry must provide total protection for the city. The economics of treatment are not considered. The rules are simple prohibitions. The city has bought a "sewage" treatment plant and by the connotation of the word believes that it is for the use of the people for treatment of body wastes and that "industrial" waste must be excluded. The treatment plant is protected by an ordinance.

Two points of vital interest: Should a sewage treatment plant be limited solely to treatment of body wastes? Will an ordinance protect a plant?

When a state agency requires treatment of a municipality's waste, it expects that the aggregate waste of the municipality will be treated. When the tax dollars are accumulated for construction of a treatment plant, industries as well as individuals contribute. It is only reasonable to expect that when the plant is designed and constructed, it should be with the object of accomplishing the

greatest good at the least cost and that it will protect the receiving stream for subsequent water uses.

This means the treatment plant should provide facilities for municipal wastes rather than human wastes alone, and that controls should be established to protect the stream.

Municipal Waste Considerations

One of the impelling reasons for a city to recognize the need for municipal waste treatment is the tax dollar. A city survives on its tax structure. It seeks diversified industry. Often these plants or shops are in areas where space for treatment facilities is not available. Prohibitions on discharge or unrealistic requirements prior to discharge can close down an operation. The answer lies in providing municipal treatment facilities in the same manner as municipal water supply without trying to set up acceptability criteria based on human wastes.

The small industrial operations connected to city sewers dump batches of acid, cutting oils, flammable solutions, oil, plating baths and other substances that do damage to sewers and treatment plants. With no alternative available, the operator will surreptitiously dump such solutions. Hauling the waste to the treatment plant would provide needed service and protection.

Many cities classify toxic wastes as those with metallic ions or cyanide. So they are excluded or drastically limited by ordinance. But there are many organic wastes, particularly oils, detergents and chlorinated organics not able to be identified by BOD or solids tests, that may damage the plant and stream. If these same wastes were bled into the plant flow rather than batch-discharged, all would benefit.

The importance of batch discharges of wastes from cities and industries on rivers has recently been well demonstrated. And the news has shown that a 24-hour composite sample of a treatment plant effluent may not be representative of its effect on a stream. A batch dump of a soluble waste could pass through a treatment plant, particularly where only settling facilities are provided, without causing plant operating control trouble but still cause much trouble in the receiving stream. The only safeguard would be collection or continuous discharge over a long period of time of strong solutions to the sewer or treatment plant.

There is also an increasing awareness that even small discharges of high concentrations of salts or toxicants to underground or surface waters may cause trouble. Discharge through a central agency, such as a municipality, could provide competent third-party control.

The most economical method for treatment of any waste is by dilution. The aggregate flow in a community provides dilution and the large volume flow from a city treatment plant promotes more adequate mixing in the receiving stream. Treatment is provided to render a waste innocuous to the subsequent water user. If the dilution capacity required is available, there is no need to add more chemicals to a stream.

What Is Municipal Waste Treatment?

Municipal waste treatment means the provision of facilities for handling all liquid wastes. It does not mean the subsidizing of an industry's treatment of its wastes. If it is cheaper for the waste to be handled by the municipality than by industry, facilities to be operated at cost to the industry are provided. The cost of construction and operation of the extra facilities is borne by the industries using them.

In many instances, holding facilities to permit a regulated and constant discharge to the municipal flow would be sufficient. In other cases, holding facilities with provisions for partial or total treatment would be needed. Mixing wastes from different sources may be an answer.

For any municipality the requirements deserve individual study.

What Are The Objections?

Proposing that a city provide municipal waste treatment raises objections that should be evaluated:

1. Would it be feasible for a municipality to provide facilities for a single industry? Would there be so many industries wishing to use the facilities that it would be impractical because of the volume and variety of wastes?

   Each city must be evaluated on its own, but some points are of general application:

   a. Hauling waste costs money. Where volume is large it would usually be more economical for the company to provide treatment at the site.

   b. Since industry pays its share, the central treatment of waste from even a single contributor may be to their mutual advantage.

   c. Few cities have a single contributor. Practically all city treatment plants have periodic difficulties which attest to the unpoliced and unappreciated small discharges. Collection and haulage to a central plant would be the answer.

   d. In many instances, understanding the objective will suggest provision of holding tanks and controlled discharge at the source when flow in the sewer is adequate.

2. Accepting industrial wastes at a treatment plant requires competent chemical analysis and increases cost to city.

   It is the sad truth that many cities have spent millions on sewers and sewage treatment plants and then have refused to hire competent individuals for their operation. A plant not well operated represents a waste of money. If this program promotes improvement in plant operation, it will give double benefit.

3. Accepting strong wastes at the treatment plant puts the burden of adequate treatment on the city.

   The city receives the benefit of the taxes and employment offered by the industry and the industry pays for the cost of treatment. The city then assumes only the responsibility of providing the treatment.

4. Treatment plants are not designed for treatment of such strong wastes. Renovation would be expensive.

   It is too true that the plants are not designed to handle the batch dumping of solutions that come to them now. It is also true that holding facilities and controlled dilution will handle many of these

wastes. The cost of additional facilities requires study in each individual city and requires a better knowledge of material discharged to the sewers than is now available in most cities. But cost should not be the result of speculation. And much of the cost will act as protection for the rest of the investment.

5. State pollution control agencies will consider such treatment facilities as a new source of waste and require new permits or controls.

   There are some states with the philosophy that all municipalities along a river must meet the same treatment requirements. These states argue they do not have to justify treatment requirements and do not have to prove resultant river quality improvement. Requirements are based on opinion, not detailed river surveys. Such states do object to this approach.

   Other states, Ohio and Indiana are two examples, recognize their responsibility in obtaining area benefit at minimum cost and have advocated engineering studies rather than "cookbooks".

   There may be a selling job needed in any given state. New ideas sometimes take time to be accepted.

6. Industry is not stable. A community may construct such facilities and then find them inoperative because of change in industry's needs.

   Engineering study will make such facilities flexible. A study of the industry in a community will indicate its stability. Arrangements on financing at time of construction will prevent loss to the city.

Municipal Sewer Ordinances

It has been truly said that uniformity is the refuge of the lazy mind. But there is the added difficulty that, under the guise of accepting the uniform procedure, the user will adopt controls without an understanding of the limitations or original scope. Such is the story of most municipal sewer ordinances.

In 1949, the Federation of Sewage Works Associations adopted and published a model ordinance. With minor variations it has been the accepted guide. But, in setting up the guide, the committee had no intention it should be unchangeable. And those who adopted its "cookbook" sections as "the code" instead of using it as the best information available at the time if its publication are the mentally lazy. So also are those who add sections on "limiting concentrations" permitted in the sewer or treatment plant without actual data on effects under local conditions. They ignore our constantly increasing knowledge. They disdain the admonition that nothing, litterally nothing, should be static if each of us is to promote the public welfare.

A municipal ordinance should promote community development not act as a shield for a lazy administrator. To develop the greatest good, the ordinance should be flexible, designate authority, outline objectives, and provide the means for accomplishment that permit administration based on engineering studies of effect and cost. With mounting cost of government, there is the added incentive that some real intelligence applied in appraising a problem will reduce costs and yet attain the desired objective.

Recommendations on making an ordinance useful and effective include:

Define municipal wastes as those liquid wastes originating within the municipal corporation or connected to its sewers and flowing from domestic, merchantile or industrial establishment.

Require controls in terms of pretreatment before discharge, regulated rate of discharge to sewers, or haulage to a treatment plant of materials in concentrations sufficient to damage sewers or treatment plant.

State that individual discharges will have to be evaluated separately and controls agreed upon. Variations in flow and other contaminants in a sewer prevent establishing a single criterion.

Do not try to write all limiting or protecting regulations in terms of specific constituents. Not all conditions can be anticipated. If a listing of limiting concentrations is considered vital, then let the ordinance designate someone to propose regulations or a guide that is not part of the ordinance and that can be changed without affecting the ordinance.

Recognize that a treatment plant should best serve the municipal need and the cost should be assessed in terms of the use of the plant. Surcharge should be computed on basis of actual cost to plant operation, not on preconceived formulas that presuppose "normal" sewage.

How Can Municipal Waste Treatment Be Sold to Cities?

The logical groups to sell this concept are the consulting engineers and state pollution control agencies. To date, few consultants have approached the problem of waste control on an area basis and few state agencies have encouraged any change in the accepted routine. This inertia must be overcome if an increasing demand for better controlled water quality is to be met.

Consultants who argue that they are employed by a city and must do as the city requests, are dodging professional responsibility and are accepting roles as technicians. When a plant is designed according to "cookbook" criteria on a population basis rather than with a recognition of the types and volumes of wastes from various sources, the end is one of convenience, not engineering. A willingness to "design" separate facilities for industrial waste can be easily motivated by the fee when it is a percentage of cost of construction.

This leaves municipalities and industries. The city administrator usually looks on sewage treatment as a burden forced on the city. If the chamber of commerce is active and imaginative, it can sell the city on the need for municipal waste treatment as an inducement for new industry. It completes the package now used to entice industry: adequate water, transportation, markets, raw material, power, labor, healthful climate.

The last salesman is the one most adversely affected by present ordinances, industry itself. What industry must learn is that insistence on provision for municipal waste treatment promotes the public welfare. Its only imposition is on tradition and lazy minds. The criticism of it well illustrates the penalty of leadership.

Questions to Ask Before Acquiring Equipment

■ WHEN THE WATER works official sets out to buy equipment for his plant, he should keep in mind that if he makes a bad decision he is going to be stuck with that equipment for a long, long time to come.

The seriousness of moving slowly and cautiously cannot be underestimated. Hasty decisions invariably mean selection of a unit whose purchase may well be regretted before it has served a single month.

A number of experts have expressed their opinions about the points every official should closely consider before purchasing equipment of any kind. Their suggestions have been summarized in the following list of questions about various pieces of equipment which may be bought in the future.

Is it economical? There's more to the problem than simply having the budget to cover the initial purchase, for each such piece of equipment must be capable of operating efficiently and economically when it is put to use. That efficiency must conform with that of others established in the plant. Its purchase should always be viewed from the standpoint of whether or not that particular unit can earn more profit than the set-up or piece of equipment now being used.

Will it handle every conceivable task in the future? Buying a unit to satisfy today's particular needs is far less profitable than selecting one which will not only handle today's requirements, but those that are probable in the immediate future as well. Replacing such units is an expensive procedure; it is not economically feasible to junk the new unit within a very short period of time in order to replace it with more adequate equipment.

Is it the most versatile unit on the market? Much as one particular piece of equipment may have outstanding features, the experts say that it always pays to investigate the product of every manufacturer in the field. After the equipment has been purchased and set-up in the plant, it is too late to replace it with a more efficient or more versatile unit. The time to make sure the very best, most efficient and most versatile piece of equipment is being bought is before the purchase order is signed.

Can the particular unit be made to get the job done? The matter of approach in considering this factor is of vital importance. Too often equipment is purchased with the thought of adapting its performance later to particular needs. Experience has shown that purchasing equipment should be studied from the viewpoint of the particular job and the equipment selected on that basis primarily. It is not considered wise to try to adapt the job to the unit but, rather, to fit the unit to the job as closely as possible. Furthermore, it is not considered wise to purchase a unit "over-rated" for a job, thinking perhaps to use its surplus performance capability for some vague future needs. Before being adapted, if ever, to this future requirement, the unit may not perform at its most efficient or economical level.

Have the desired specifications been set-up? Writing the specification should be the first order of business after the decision to buy has been made. And this should be set down on paper, for such specifications become vague when left to memory and are apt to be influenced by the sales pitch of the equipment salesman.

Is every manufacturer's product being considered? The wise investment of such long term capital funds necessitates the purchaser to make certain that he has information concerning every manufacturer's unit before him at the time the final selection is made. This is one time it pays any official to make certain no unit of outstanding merit has been overlooked in consideration of the equipment that is about to be purchased.

Will the unit under consideration fit into use with other pieces of equipment presently installed? The investment in this single purchase is small in comparison with the over-all investment in the plant itself. It is far less expensive to buy a unit which fits into the present flow of work than one which will require vast and expensive changes in the plant as it exists today. Versatility is desired to not only fit perfectly into the present set-up but to lend itself to future replacement of other units in an effort to increase over-all performance figures.

How high a degree of accuracy exists in the unit? We cannot afford to sacrifice any degree of accuracy today for price or any other consideration. The competitive trend for the future is definitely toward perfection. Such high degree of accuracy also assures top performance at all times and also is an asset in permitting use by less skilled personnel in emergency.

What degree of quality workmanship exists in the unit? Good workmanship in the essential parts increases equipment life and reduces troubles, breakdowns and inaccuracies. There is no real substitute for quality in any piece of equipment. Other concessions serve only to cover up this important asset. Where quality workmanship is lacking, useful life always is reduced and that means the unit costs more in the long run than purchase of a top quality product.

Simplicity of construction? This is a most important asset for it determines not only how easily the unit may be operated but high or low cost in disassembly and re-assembly, repair and maintenance. This asset, however, should always be viewed from the standpoint of how high a degree of quality can be obtained with such simplicity of construction,

and never from the standpoint of simplicity alone.

How reliable is the unit? Taking chances, to save initial investment, on the performance reliability of any unit never saves money but only adds to the year-in and year-out cost of use of the equipment. Dependability and reliability are musts for any piece of equipment.

Is it easy to maintain and repair? This factor should always be given close scrutiny. A piece of equipment which needs special repair service or time-consuming maintenance every time it is out of order is definitely less desirable than one which can be serviced, maintained, and repaired with speed and low cost. Any design is undesirable which causes cumbersome work in dismantling and replacing or which involves extended delays in obtaining such service.

What will be the installation cost? This is, so say the experts, the most frequently overlooked point in equipment replacement consideration. Many a unit which appears less expensive turns out to be the most costly of all by the time it has been installed and put into use. The cost of installation should always be considered in analyzing such pieces of equipment of any kind.

How safe is the unit? Sometimes manufacturers find they can keep costs down below the competitive average by sacrificing safety features or specifying these as extras to the purchase price. In any unit where there are more than the usual danger points and additional protective devices are exceptionally expensive or will not fully cover the dangers, it is best not to buy such unsafe units.

Will it fit into the available space? Space, weight and heights are all important considerations. Where the unit will require major structural changes or additional space, this cost factor must be taken into consideration in choosing between one product and another.

There are, of course, other factors which pertain to each specific unit, but the foregoing considerations represent points which every official can well apply to the purchase of any piece of equipment as factors of basic consideration.

A check list to determine something about . . .

How You Rate as a Boss

by ERNEST W. FAIR
Boulder, Colorado

EDITOR'S NOTE: There is hardly a supervisor alive who at one time or another has not wondered about his ability as a boss. To help answer this question WATER & SEWAGE WORKS presents this list of twenty-five pertinent and revealing questions. As a guide for rating your answers to these, the following criterion is suggested: if you have 20 to 25 "yes" answers, you are a definitely above average boss; 15 to 20 makes you quite average, while anything below 15 would indicate that an examination of your methods might be in order. How do you rate as a boss?

1. The last time I corrected one of my men for something for which I found later he was not responsible, I immediately apologized to him.

2. I have a policy in my department that any individual can talk to me at any time about anything concerning the department, his job, etc.

3. Whenever an unpleasant situation arises in the department, I step forward and assume the responsibility rather than try to alibi it off as the fault of one of the men.

4. Every one of my men knows and understands that I realize they are human and expect them to make mistakes from time to time, but they know also that I will not tolerate too many such mistakes.

5. It is my policy that an employee can always bring his personal problems to me and I will do my best to help or at least to point out the way to get help. It is also my policy, however, that when I know beforehand such problems exist, I will never interfere unless first asked to do so.

6. No employee has ever been discharged without good cause and without a fair hearing.

7. When disputes arise between men in different parts of the department, I always arbitrate the problem for the good of the department without taking sides.

8. I make it a point always to compliment a man when he does something not required by his regular job.

9. I always see to it that a man is remembered upon important personal occasions.

10. I never high-pressure my men into contributing to my favorite charities or those of my friends.

11. I have a policy in my department that no one in authority will tolerate gossip by one employee concerning another.

12. I will make every effort to avoid playing favorites among my men in any manner, shape or form.

13. I make it a point to be absolutely certain that paychecks are correct.

14. In times of real emergencies, I see to it that the man involved is given time off without loss of pay.

15. When I add a man for a given job, I do not expect him to do other jobs when things are slack unless this has been understood beforehand.

16. If we have a month or two of heavy activity and the staff has worked extra hard to take care of it, I always see to it that they are rewarded in some manner or form.

17. When I give specific authority to anyone on the staff, I make it a point to always back up that authority.

18. When people have compliments for our department, its services, or for an individual employee, I always see to it that these are passed on to everyone on the staff.

19. I never ask any man to do anything that I would not be willing to do myself.

20. When corrections are handed out, I make it a point to talk with the man involved in privacy.

21. When special commendation or praise is to be given any man on the staff, I see to it that this is done in front of the others.

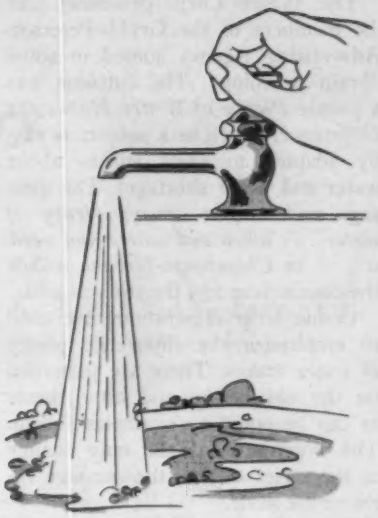
22. If I suspect that something is wrong involving some member of the staff, I investigate myself and do not seek the information from among other employees mentioning that individual by name.

23. No matter how many departmental worries I have at any particular time, I keep these to myself and do not burden the employees with them, for after all they are my problems and not those of my employees.

24. I never discuss my employees with others unless I have something nice to say about them.

25. I have learned to control my temper in my dealing with my employees no matter how childish a mistake one may have made.

PLENTY OF WATER makes the difference



And there's always plenty of water . . . when and where you need it . . . in Champaign-Urbana . . .

by EDWARD R. HEALY, Vice President & Manager, Northern Illinois Water Corp., Champaign, Ill.

EDITOR'S NOTE: The public is not aware of its need for good, safe, dependable water service—until it is without. This article tells of a company's efforts in public relations to demonstrate this need by comparing where they would be without water.

■ PUBLIC RELATIONS in the water works industry has long been a subject for concern. This was the case with the Northern Illinois Water Corp. who, like many others, only heard from the customer when he had a complaint.

The company has always maintained an active interest in public relations. In addition to conducting tours of the plant and facilities for University of Illinois and high school students, Chamber of Commerce community affairs and educators themselves, the company placed ads in two local newspapers. These ads were run for many years but received little or no public response.

Newspaper advertising was considered a good media for reaching the people, to keep them informed on what their water company was doing, intended to do or had done. Apparently something was wrong with the ads because no interest was generated by them.

Although the ads were seldomly professionally planned, each was directed toward some phase of the local operation or construction program. New facilities were pictured along with copy explaining possibly a new facility or some other phase of the water service operation such as pumping, treatment, etc. Attention was directed at the ever ready fire protection; the dependable water supply. Apparently the ads were too technical, too long and too detailed for the average newspaper reader to become interested in or take time to read.

The ads were run weekly in each of the two Sunday newspapers. This was a burdensome job in itself, but without public response, it became even more difficult. The ads were definitely informational in character and the ownership and management wanted to display its proud record of service to the community. Never was there one instance of water shortage which was not the case among neighboring communities. The company wanted the public to realize this and other facts but the ads just weren't reaching them.

At this time, which was a few years ago, an advertising agency was retained to give advice and assist in the preparation of ads. Unfortunately this was not the full solution because the agency could only reflect the ideas given it and these were not changed.

The management decided to evaluate the many ideas which it was trying to put across. An eye catching ad was desired; one that was attractive; could be recognized at a glance; would carry a definite message and could be presented as a series. Apparently one secret to modern advertising is to hammer home one message over and over again.

The Water Corp. personnel and the members of the Grubb-Peterson Advertising Agency joined in some "brain storming". The outcome was a phrase *Plenty of Water Makes the Difference*, which as a subject is easily adapted to news stories about water and water shortages. The message *and there's always plenty of water . . . when and where you need it . . . in Champaign-Urbana* makes the comparison and the story is told.

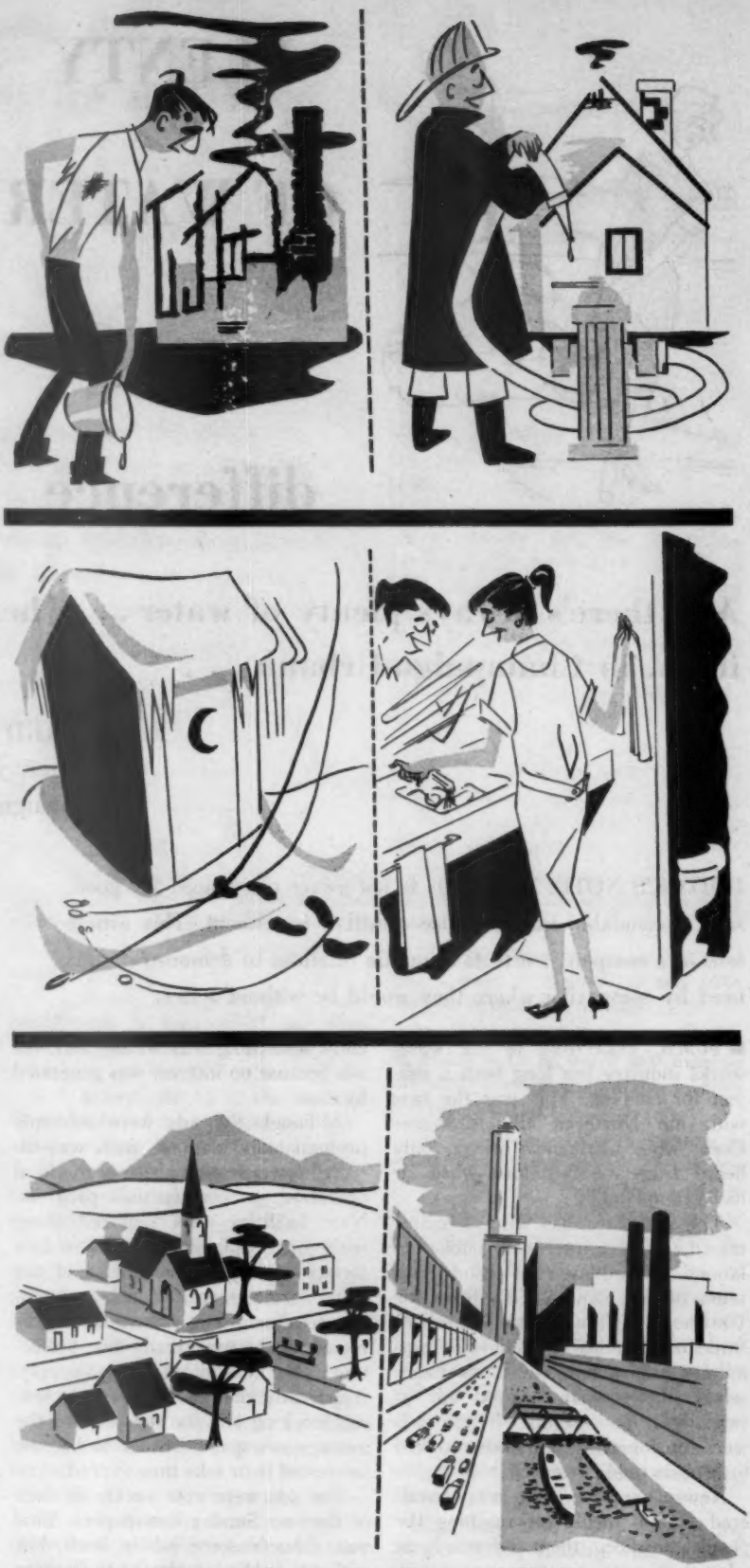
Comic strip illustrations are used to emphasize the difference plenty of water makes. These are patterned on the old before and after theme as can be noted by examples shown. The illustration is the only change in the series of ads, the message remains the same.

The ad series is planned for 26 ads. Each ad costs somewhere in the range of $175.00 when it finally gets into print. This is a rough estimate which includes agency fees for all advance planning, monthly planning, technical and production costs, plus newspaper space. The ads are not used on a mass volume basis, if so, the cost per ad would be even lower.

Because of budget considerations the ads are now run once every two weeks rather than the weekly schedule previously practiced. Also the day for running the ad has been changed from Sunday to Saturday in hopes of attracting more attention. Although the Sunday readership is larger, the chances of the ad becoming obscured among the voluminous advertising seemed more apparent than if placed in the smaller less crowded Saturday papers. It was felt that a larger number of the Saturday readers would notice and read the ad thus actually giving better coverage.

The response has been the best ever experienced. People say they look forward to the next ad to see what will come up as an illustration.

Our comments, of course, come from business, social or civic contacts because true public response is difficult to determine. As any water works man knows, it is seldom one hears from a pleased or satisfied customer since good service is taken for granted. Our educational accomplishments through public relations have not overcome this obstacle yet, but the company is happy to report that not one negative response has been received.



CARTOON TYPE illustrations are changed in each ad. These are some examples.
The Grubb-Peterson Advertising Agency, Champaign, Ill. is authorized to release these ads to any interested Water Utility.

What are equitable rates and charges for . . .

Sewer Service Cost *to industry*

by GEORGE K. ERGANIAN, Exec. V.P.
Henry B. Steeg & Assoc., Inc.

EDITOR'S NOTE: The subject of equitable charges for sewer services to industry has received considerable attention. The literature contains many reports on rate structures based on volumes and concentrations of the wastes involved. In the State of Indiana, rates are established strictly on a water usage basis.

By presenting a hypothetical situation the author shows the inequities of this method and how water usage rate structures adversely affect commercial and industrial consumers.

■ THE DEVELOPMENT of rate structures has for the most part followed the reasoning that the rates and charges are intended to cover the cost of constructing and operating a sewage treatment plant and interceptor sewer system. Under this condition the development of a rate structure based on volume of flow, and including surcharge rates for abnormal concentrations of industrial wastes is reasonable. Methods of determining these surcharge rates to industry involve the allocation of the cost of both the construction and operation of the facilities required for handling 1) flow, 2) solids, and 3) BOD.

Examples of computations presented in the literature are worthy of attention and understanding, since they represent rational methods of allocating the fair cost of waste treatment to the industries involved. While it is not the intention of this paper to discuss this phase of rate making, it might be noted, in the way of confirming the opinion of other authors, that the use of a surcharge formula has certain practical limitation, particularly from the administrative cost angle, and as a result there are very few instances of such surcharge rates being imposed on industry in Indiana.

The principal concern of the writer and the theme of this text is the fact that there has been a gradual distortion of the basic premises of rate making for sewer service in Indiana. For years the fact has been recited that the cost of constructing and operating a sewage works is directly related to flow and concentration of wastes to be treated and that equitable charges to a customer for the service should therefore be based on the volume and concentration of wastes discharged by that customer. In order to describe some of the inequities which may arise from the indiscriminate use of this philosophy, it is necessary to first describe the statutes under which municipal sewage works projects are being built and financed in Indiana. The fact this discussion regards conditions as they exist in Indiana is stressed. Methods of financing vary from state to state, and the conditions to be described may or may not apply in other areas of the country.

Practically all of the cities and towns in Indiana, (with the exception of Indianapolis, Gary, Richmond, East Chicago, and Hammond, which operate as Sanitary Districts) have financed the construction of sewage treatment facilities hrough the issuance of sewage works revenue bonds, under the authority of the Sewer Service Charge and Revenue Bond Act, Chapter 61, Acts of 1932. This Act has been amended and supplemented in practically every session of the legislature since the special session of 1932.

While the Revenue Bond Act was enacted originally to provide a method for cities and towns to finance the cost of interceptor sewers and sewage treatment facilities, the authority to ". . . construct, own, equip, operate, maintain and improve works for the treatment and disposal of sewage . . ." was soon implemented by an amendment to the original Act which defined the term *works* to include not only the sewage treatment plant and interceptor sewers, but also main sewers, submain sewers, local and/or lateral sewers, outfall sewers, force mains, pumping stations, ejector stations and all other appurtenances necessary or useful and convenient for collection and treatment of sewage.

A revenue bond financed sewage works project will (except under certain rare circumstances) include the construction of, or improvements to, a sewage treatment plant. In addition, however, it may (and very often does) include trunk sewers, relief sewers, and local sewers. If the original system was of the *combined* type, that is, one sewer providing for the collection of both surface water and sanitary sewage, then the proposed sewer extensions or relief sewers may also be combined sewers.

In the author's opinion the enlargement of the scope of the Act, was a

Presented at 14th Industrial Wastes Conference, Purdue University, printed here with permission.

perfectly reasonable and normal process of evolution. Plants and interceptor sewers were being readily financed to serve existing sewered areas, but municipalities found themselves with large portions of their community remaining either totally unsewered or inadequately sewered. In many communities it was almost, if not actually, impossible to undertake major sewer system expansion projects under available methods of financing. Regardless of one's position as a citizen, as a public health officer or as a municipal official, this situation had to be resolved, and the simplest method was to enlarge the scope and intent of the Revenue Bond Act.

Under the present broad interpretation of the Act, many projects today include the cost of sewers, other than interceptor sewers, which may equal or exceed the cost of the treatment facilities. It is this particular type of project in which the application of rates based on water use sometimes result in an injustice to some large water using industries. To illustrate this, a hypothetical case is described as follows:

A City of say 10,000 population is undertaking the construction of a sewage works project which will cost as follows:

Plant	$ 500,000
Interceptor	$ 200,000
Trunk Sewers	$ 500,000
Relief Sewers	$ 800,000
Project Cost	$2,000,000

This type of project might conceivably be undertaken by a rapidly growing community whose immediate needs include: 1) a sewage treatment plant and interceptor sewer, 2) the extension of trunk sewers to newly annexed areas, and 3) the relief of existing main trunk sewers.

In this case, it is assumed that existing water rates are extremely low, and as often happens in such cases, the spread between the high and low brackets as shown is not very great. These rates are:

First 5,000 gal. @ 15c 1000 gal.
Next 20,000 gal. @ 12c 1000 gal.
Next 25,000 gal. @ 10c 1000 gal.
Over 50,000 gal. @ 9c 1000 gal.
Minimum Rates: 45 cents per month for 3000 gal.

In this particular community it is assumed that there are 2940 residential and commercial customers, using an average of 4000 gal of water per customer per month. In addition to this, it is assumed that there are 123 industrial customers with the following average water consumption requirements:

Customers	MGD of Water
1 using	0.2
1 using	0.05
10 each using	0.01
111 each using	0.001

Based on the project cost previously illustrated, annual revenue requirements might be:

Amortization of Plant and Interceptor	$ 58,000	
Operating Cost of Plant	22,000	$ 80,000
Amortization of Cost of other Sewers	$108,000	$108,000
Total Annual Revenue Required		$188,000

Volume of flow received at the plant is assumed at 1 mgd, broken down as follows:

Residential and Commercial	0.392 MGD
Industrial	0.461 MGD
Infiltration & Unaccounted	0.147 MGD
Total Flow to Plant	1.000 MGD

Revenue required to meet the cost of amortizing the investment and the cost of operation and maintenance is $188,000 per year or approximately five times the revenue from the sale of water. Following a commonly employed procedure, the sewer service charge rate structure is established by retaining the same water rate blocks and increasing the charge per 1000 gal by five times. The rate structure for sewer service charges is then:

First 5,000 gal/mo. @ 75c 1000 gal.
Next 20,000 gal/mo. @ 60c 1000 gal.
Next 25,000 gal/mo. @ 50c 1000 gal.
Over 50,000 gal/mo. @ 45c 1000 gal.
Minimum charge $2.25/mo.

Assuming the average amount of water consumed per residential customer is 4000 gal, average residential rates will be $3.00 per month and total revenue received per year from the 2940 residential and commercial customers $106,000. The remaining $82,000 per year will be derived from the 123 industrial customers as follows:

1 at 0.2	MGD @	approx.	45c/1000 gal. =	$32.400/yr.
1 at 0.05	MGD @	approx.	46c/1000 gal. =	8,300/yr.
10 at 0.01	MGD @	approx.	47c/1000 gal. =	16,900/yr.
111 at 0.001	MGD @	approx.	61c/1000 gal. =	24,400/yr.
			Total	$82,000/yr.

Statistical Summary of Situation

Predicated on the assumed conditions heretofore established, the following significant statistics shown in Table 1, can be computed.

Discussion of Statistics

On the premise that the cost of trunk sewers, and general relief sewers are costs of general benefit which should be shared by the whole community on an ad valorum tax basis, the previous computations might be utilized to examine the equity of the rate structure to major water using industries of the community.

For instance, the principal industrial water consumer of this hypothetical community paid $2700 per month for sewer service, or a total of $32,400 per year. Since 51.5 per cent of this revenue would go toward the cost of trunk and relief sewers, this industry would be paying $16,700 per year toward the cost of these general improvements. Assuming that these general improvements had been paid for by taxation, the assessed valuation of this industry would have had to be $1,940,000 in order to raise the amount of $16,700 by an 86 cents/$100 tax levy (the same tax levy computed for the average residential customer).

On the same basis, the industry using 50,000 gal per day of water would have had to have an assessed valuation of $555,000; the industry using 10,000 gallons per day, $113,000; and the 111 concerns using only 1000 gallons per day, $14,600.

Needless to say it is highly improbable that each industry would fall into the proper water use—assessed valuation category. On the contrary, it is much more likely that this rate structure would result in glaring inequities. For example, think of small dairies, metal platers, canners, laundries, automatic car wash operations, and others in these catagories using anywhere from 100,000 to 1,000,000 or more gallons of water per month which could be badly hurt under the conditions described.

Fortunately, the circumstances described in this case are somewhat extreme, and have been used merely to illustrate the problem. The fact remains, however, that as long as rate schedules are based on water usage,

TABLE I

1. Cost of Amortization of Plant and Operation

Per Mil. Gal. Sewage Treated ..... $ 218
Per 1000 gal. Sewage Treated $0.218

2. Charge to Average Residence

Per 1000 gal. $0.75
Per Month $3.00

3. Allocation of Residential Revenue

To pay for Sewage Treatment ..... $\frac{0.218}{0.75}$ 29.2%

To pay for Sewers ..... $\frac{0.75 - 0.218}{0.75}$ 70.8%

4. Assuming Average Assessed Valuation of Residential property at $3000

Sewer service charge payment toward sewers is equivalent to tax levy of 86 cents/$100

5. Cost to Industry, per 1000 gallons

a. Customer using 0.2 MGD 45c
b. Customer using 0.05 MGD 46c
c. Customer using 0.01 MGD 47c
d. Customer using 0.001 MGD 61c

6. Allocation of Industrial Revenue	Percent of Revenue	
	To Pay for Plant	To Pay for Sewers
a. Customer using 0.2 MGD	48.5	51.5
b. Customer using 0.05 MGD	47.5	52.5
c. Customer using 0.01 MGD	46.5	53.5
d. Customer using 0.001 MGD	35.9	64.1

there is little hope that completely equitable rate structures can be devised in cases where major sewer improvement projects are financed under the existing sewage works revenue bond statutes of Indiana.

Summary

In summary, it is noted that because of the lack of other suitable methods of financing, Indiana communities have undertaken major sewer improvements together with the construction of sewage treatment facilities under the provisions of the Sewer Service Charge and Revenue Bond Act. These sewer improvements, most of which might otherwise have been paid for through taxation, are generally included in establishing the rate base. Under these conditions charges levied strictly on a water usage basis cannot help but be inequitable, this inequity being more pronounced among the commercial and industrial group of consumers.

The problem of flooding of an industrial park at Hartford, Conn. was solved by

Two Storm Water Pumping Stations

by ROBERT DYMENT,
Magazine and Newspaper Writer,
Dunkirk, N.Y.

RESUME: The elevation of the North and South Meadow sections of Hartford, Conn. is below the level of the Connecticut River at most river stages. Since the entire city is separated by a system of dykes from the river all of the storm water collects in this area from which it must be pumped over the dykes to the river. As the existing pumping station did not have capacity to cope with the larger storms plans to convert the Meadow into an industrial park required the construction of new pumping stations. These new stations are equipped with ten diesel driven pumps with a capacity of 375,000 gpm which is in excess of the runoff from a ten year storm. These stations are the largest of their type in the east and are designed to operate if necessary without outside power and with a minimum of manpower.

■ IT WASN'T so much the river as the land that was causing trouble in North and South Meadows, the lowest sections of land around Hartford, Connecticut.

Five miles of dikes restrained the Connecticut River. They offered protection against a river depth up to 45 feet. But this didn't keep the Meadows dry. Excess water falling within the Hartford area drained into these two areas. And the existing pumping stations which had a total capacity of only 108,000 gallons per minute couldn't handle all the water. Capacity to move a minimum of 216,000 gpm. was needed.

The situation was serious not only because it involved lives and property, but because Hartford wanted to develop North and South Meadows as Industrial Park Zones in order to bring new industry into the area.

Flooding today is a serious problem with many cities and communities throughout the nation and no city knows better than the New England City of Hartford, Conn. It suffered untold losses in the 1955 hurricanes which ripped through their city and surrounding areas.

More Capacity Needed

The city administration determined to see that such a disaster doesn't happen again, at least as far as flooding is concerned took steps to protect the area by installing an entirely new storm water pumping system, which included the installation of diesel engines in one of the largest installations of its type in the eastern United States.

By installing 10 Caterpillar D397 diesels to drive the existing pumps at higher speeds, Hartford was able to boost pumping capacity to 375,000 gpm, which gives them a comfortable safety factor. The diesels were installed in the modern South Station

FIG. 1. AN EXTERIOR VIEW of one of the two pumping stations at Hartford, Conn.

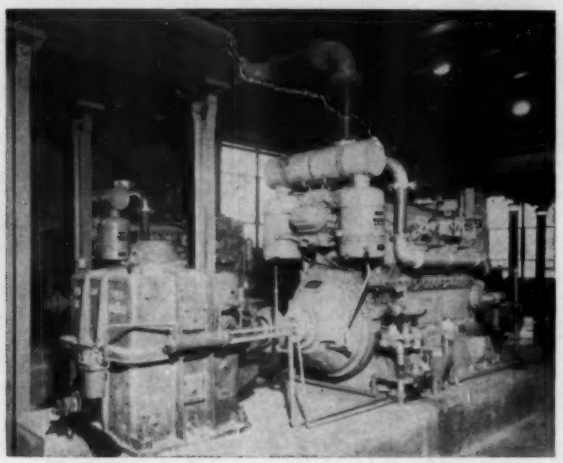


FIG. 2. GENERAL VIEW of some of the V-12 Diesel Engines and gear heads located in the North and South pumping stations.

FIG. 3. THE DIESEL POWERED GENERATOR, shown center, powers the air compressors for starting the diesel prime movers at the city of Hartford's south pumping station. This electric set also furnished power to operate the flood control gates in event of a public power failure.

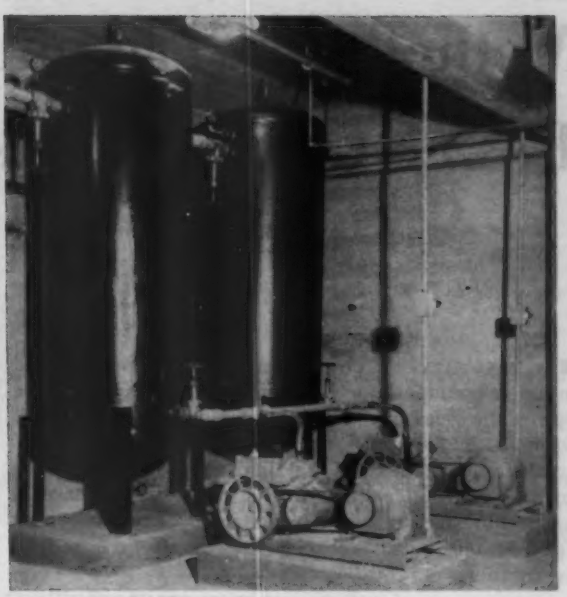


FIG. 4. TWO ELECTRIC POWERED air compressors and storage tanks supply compressed air for starting motors on the V-12 diesel engines at the city of Hartford's pumping station.

and North Station at Hartford.

As mentioned, five miles of dikes protect the City from the Connecticut River during flood stage. Two storm water pumping stations lift the water from back of the dike into the river. The dike gives protection to a river height of 45 ft. South Meadows Pumping Station, because of the lowness of the land, has to start pumping when the river reaches elevation 8 ft. The storage pond elevation is kept down to about elevation 5 ft. North and South Meadows are the lower sections of the Hartford area. Storm water runoff and drainage within the Hartford area runs to this sections and must be pumped out.

North and South Meadows are two miles apart. Previous to the installation of the ten diesels, the pumps were operated by electricity and gasoline engines.

The reasons for the change was twofold: More capacity was needed at higher river levels after experiencing the 1955 hurricane, the gas engines were becoming obsolete and parts were hard to obtain. The City changed to diesels, upped the horsepower on the engines to drive the impellers of existing pumps faster in order to obtain more capacity at higher river heads.

Another important reason for the change was the development of North and South Meadows. These two areas were made industrial Park Zones designed to attract industries to Hartford. As a result of the improvement to the pumping stations, they now get rid of water much faster and stay ahead of water coming in. If this pumping arrangement had existed in 1955, the flooding would not have occurred.

The pumping capacity is based on the intensity of a 10-year rainfall as determined from a curve developed from a 35 year record.

South Pumping Station

Four 38,000 gpm and two 37,000 gpm pumps give this station a capacity of 226,000 gpm at the required 30 ft head. These pumps as well as those at the North Pumping station are driven by Caterpillar D397 diesels with Rotts type blowers through Philadelphia Gear Works reduction gears. The station is equipped with a Cat D318 generating set. This unit is to provide emergency power for the starting air compressors and for operating the flood gates. At the south station eight gates are already installed and two more are to be added. Operation of the station during the period that it will be needed most will probably call for the use of this emergency equipment. A 20,000 gal fuel storage system is also provided at this installation.

North Pumping Station

This unit contains four pumps with a combined capacity of 151,000 gpm which is provided by three 38,000 gpm pumps and one 37,000 gpm capacity unit. Facilities for the storage of 10,000 gals of fuel is provided and a gasoline driven standby generator will provide emergency power.

Each engine in both pumping stations is equipped with heat exchange fresh water cooling regulated to conserve city water. Twin disc clutchs were installed. In the event of high cooling water temperature, low oil pressure or overspeed an audio visual alarm system provides a warning before the safety system automatically takes the engine out of service. Starting air is supplied by dual compressors with a 32 cu ft receiver. The exhaust noise level is controlled by silences. Three pumps are DeLaval 36 in. 35,000 gpm pumps and seven are x 36 in. Morris Machine units of the same output.

Metcalf and Eddy were consulting engineers on the project which will protect Hartford from storm water problems for many years.

Method For Tripping Power Circuit Breakers

by H. B. ASHENDEN
Engineer,
Allis-Chalmers Mfg. Co.
Boston, (Mass.) Works

■ A MAJORITY of power circuit breakers are held in the closed position by a mechanical latch and are opened by releasing the latch by movement of a small solenoid or solenoids. In most cases the plunger or armature of the small solenoid actually strikes the latch or trips it by impact. For this reason it is customary to state that a breaker is tripped rather than opened. The small solenoids are usually referred to as trip coils.

Some source of energy is necessary to operate these small solenoids. It must be dependable and available at all times regardless of any fault or other abnormal condition on the line protected by the circuit breaker. Fundamentally, the method of tripping is determined by the source of energy regarded as satisfactory for the particular application.

Only three sources of energy are regarded as sufficiently reliable for tripping power circuit breakers during fault conditions. They are: a. energy from a storage battery, b. energy from a capacitor, or c. energy from a current transformer.

In place of "c" it is possible to use a coil connected in series with the line to energize the small tripping solenoid. For practical reasons, including the difficulty of satisfactory insulation, series coils are usual practice only on low voltage power breakers rated 600 volts or less. At higher voltages, current transformers which provide a small low voltage current proportional to the primary current are safer, more practical, and customary.

Breakers may also be opened by energy from a low voltage ac source but this is not considered reliable during abnormal conditions. Low voltage ac trip is used only for switching in combination with "c" above. The reason for regarding this source of energy as unreliable is obvious since a low voltage ac source is almost invariably tied in directly or indirectly with a circuit which the breaker is protecting. During a severe fault, voltage may become very low with the result that energy to trip will not be available when it is most needed.

Tripping Method Described

The various types of tripping commonly available in modern power circuit breakers may be conveniently classified as follows:

1. Tripping from energy supplied by a storage battery controlled by relays. This is commonly referred to as "dc trip," Fig. 1.

2. Tripping from energy supplied by a capacitor charged from a low voltage ac source and controlled by relays. This is usually called "capacitor trip," Fig. 2.

3. Tripping from energy supplied by current transformers connected directly to small trip solenoids without control by relays. Time delay may be provided by dash pots attached to plungers of solenoids. The

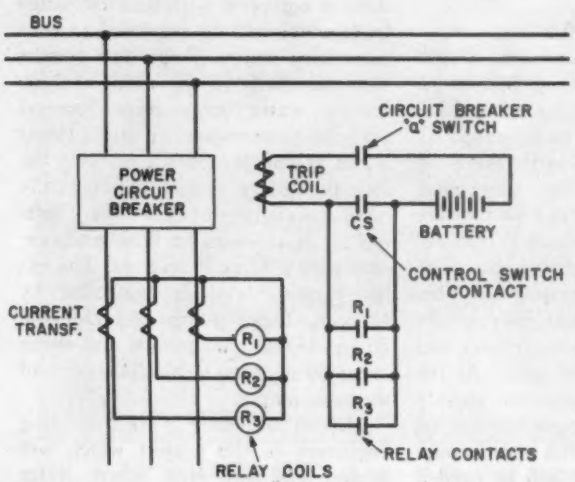


FIG. 1. DC TRIP with overcurrent relays.

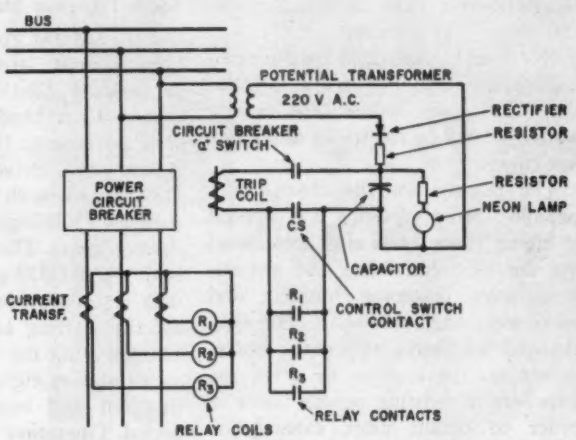


FIG. 2. CAPACITOR TRIP shown with overcurrent relays; more complex types of relays may be used.

dash pots may be hydraulic or air. Clockwork mechanisms are sometimes used, Fig. 3.

4. Tripping from energy supplied by current transformers controlled by circuit closing relays and reactors, Fig. 4.

5. Tripping from energy supplied by current transformers controlled by circuit opening relays, Fig. 5.

6. Tripping from energy supplied by low voltage ac source, usually used only for switching but occasionally controlled by ground relays. Three, four and five are usually referred to as "current transformer trip" but can also be identified as "ac trip." Number six is customarily "ac potential trip."

Not all of the above types of trip are available in all sizes and types of breakers. Usual practice of the various power circuit breaker manufacturers differs a little but in general the following is customary:

For large outdoor oil circuit breakers, rated above 69 kv, only number one is available.

For intermediate voltage outdoor oil circuit breakers, rated 23 through 69 kv, numbers one and two are usually available although number one is preferred and customary. All types of trip are available for small outdoor breakers rated at 15 kv. The same is true for indoor oil breakers, rated 15 kv and below.

Numbers one and two are usually used for magnetic breakers rated 5 kv although all methods of trip are available. For larger breakers of this type, rated 15 kv, only numbers one and two are offered.

Application Determines Trip Method

Method of trip to be used depends on the application and each one should be considered individually. Sometimes the opinions of the user are the deciding factor where any one of several methods may be considered adequate. Among the factors which should be noted for each application are the location of the breaker with regard to the system; the size and type of breaker, whether it is a large station with many breakers or a single breaker in an unattended substation, or if it is an entrance breaker for an industrial plant.

In addition, there are the degree of accuracy and selectivity deemed essential, reliability required, and the cost considered justified. Of these, cost is perhaps most important, otherwise number one would always be used. Number one is regarded as the most reliable method and can provide the ultimate in accuracy, selectivity, and degree of protection if relays are correctly applied. It is also, however, often the most expensive, especially where only one or a very few breakers are installed.

In large stations with many breakers a control battery is provided for all control functions and all breakers are tripped by energy from this battery as a matter of coruse. In isolated locations with only one or a very few breakers, one of the other methods of trip from an ac source will often be entirely adequate. The relatively large cost of a storage battery, plus charger, installation, and maintenance will not be economically justified.

A few statistics indicating the consensus of opinion of a considerable number of users of circuit breakers may be of interest. These figures were compiled from

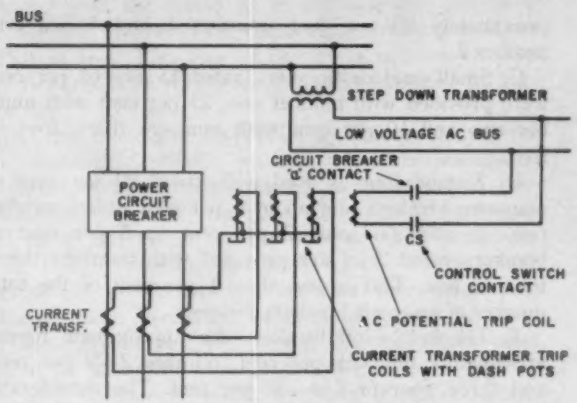


FIG. 3. CURRENT TRANSFORMER trip without relays.

a survey of a large number of breakers of all types shipped during 1956 and 1957. Although the relationship may have deviated a little since, there appears to

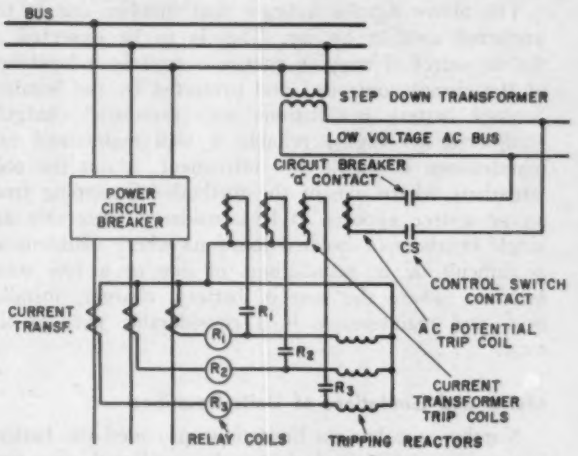


FIG. 4. CURRENT TRANSFORMER trip with circuit closing relays and tripping reactors.

be no important change:

A. Large outdoor breakers, rated above 69 kv—all number one.

B. Outdoor breakers, rated 23 through 69 kv, ap-

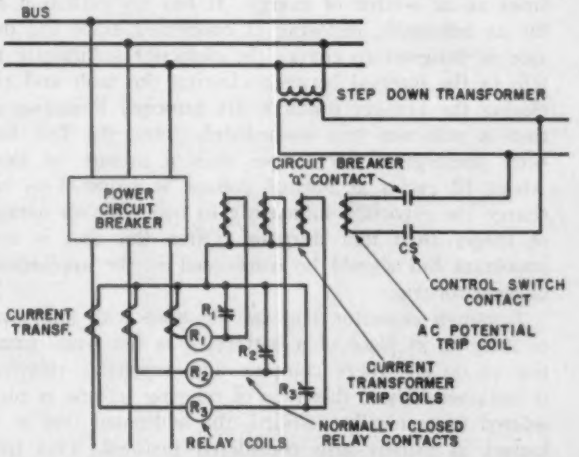


FIG. 5. CURRENT TRANSFORMER trip with circuit opening relays.

proximately 99 per cent—number 1 and 1 per cent number 2.

C. Small outdoor breakers, rated 15 kv—65 per cent were provided with number one, 25 per cent with number two and 10 per cent with numbers three, four or five.

D. Number one is used with about 94 per cent of magnetic breakers and about 6 per cent utilize number two. In addition some 2 per cent to 3 per cent of breakers rated 5 kv are provided with numbers three, four or five. This is less than 1 per cent of the total number of magnetic breakers shipped.

E. On indoor oil breakers the approximate figures are number one—55 per cent, number 2—9 per cent, and three, four or five—36 per cent. The considerable use of three, four and five on these indoor breakers is due to the rather large number of small manually operated breakers, approximately 30 per cent of the total. Many of these were furnished with number three, as has been the case for many years.

The above figures indicate that number one is the preferred method by far. This is to be expected as the dc source of tripping energy is entirely independent of the circuit controlled and protected by the breaker. Storage battery installations with associated charging equipment are highly reliable if well maintained and maintenance is simple and infrequent. About the only situations where one of the methods of tripping from an ac source appears to be considered preferable are single breakers in isolated locations where maintenance is difficult or in installations of one or a few small breakers where the cost of battery, charger, installation, and maintenance is a considerable part of the total.

Merits and Limitations of Units Described

Number one has no limitations provided the battery is properly maintained. It can be used with any type of relaying and is quite generally regarded as the most reliable. However, unless the battery is already installed and available for tripping additional breakers it will have the highest overall cost.

Number two can also be used with any type of relaying and is most versatile of the methods of tripping from an ac source of energy. It has no limitation as far as automatic reclosing is concerned since the device is designed to charge the capacitor sufficiently to trip in the interval between clearing the fault and reclosing the breaker contacts. Its principal limitation is that it will not trip immediately after the line has been deenergized for longer than a minute or two. About 12 cycles at normal voltage is required to recharge the capacitor sufficiently to trip after an outage of longer than that duration. Often this fact is not important but should be considered in the application of capacitor trip.

Although capacitor trip can be used with any type of relaying in place of a battery, it is not usual practice to do so where complex and expensive relaying is installed. Where this type of relaying scheme is considered economically justified, the additional cost of a battery is usually also considered justified. This trip has a lower first cost than number one because the battery is not required.

Number three is the most economical method since neither relays or battery are required but it is also the most limited. It is quite dependable since the energy to trip comes from the fault current itself and is useful where the only requirement is that the breaker shall trip an overcurrent after some time delay. The principal limitation is lack of accuracy in time settings because the dash pots used to provide time delay are much less accurate than overload relays and selectivity is consequently poor. It is not recommended for those applications where it is necessary to coordinate the tripping of the breaker with other devices. Nevertheless number three is useful where its characteristics are adequate and more refinement is not economically justified. Principally it is used with small isolated manually operated breakers.

Number four is similar to number three in that it derives energy to trip from the fault current but avoids some of the limitations of number three since overcurrent relays are used to obtain accurate current and time settings. Selectivity is thus relatively good. The usual limitation of all current transformer trip schemes which should be used only where it is adequate to determine selectivity by time and magnitude of current is true here, too. Its other limitation is the high burden imposed on the current transformer, approximately 6 ohms, by the reactors.

Number four should be used only where current transformer capacity is ample and fault currents are expected to be high. Cost is, of course, higher than number three since relays must be purchased and installed.

Number five is similar to number four except that burden in current transformers is relatively low and it is therefore, satisfactory for use with bushing type current transformers. The secondary current, which the circuit opening contacts of the relays transfer, should be less than about 100 amperes. Roughly, number five should be used where the secondary currents, due to faults, are expected to be low, and number four where they will be high. The circuit opening relays for number five are usually a little more expensive than the circuit closing relays of number four.

Number six is generally used only for switching and is never recommended for automatic tripping on faults because of the possible low voltage during a fault. It is sometimes used in combination with four or five for tripping from ground relays on the assumption that any ground fault which is high enough to seriously reduce the voltage of the breaker will operate one of the phase relays. Ground relays can be and often are used with schemes shown in Figures one, two, four and five but were omitted from these figures for simplicity.

Battery Installation Vary With Application

Batteries customarily installed with switchgear for dc trip and other control functions are storage batteries of the lead-acid type which have time-proved reliability and long life. Standard voltages are 48, 125 and 250 with 24 being used occasionally. This type of battery is quite large and heavy and requires some sort of housing which means relatively high installation cost. Where economy is necessary and the only

function of the battery is to supply energy for dc trip, it is possible to retain many of the advantages of dc trip at somewhat less cost by using another type of battery.

For very small isolated breakers, one or more dry cell 45-volt "B" batteries of good quality may suffice. A disadvantage is that they must be replaced every 6 to 8 months. This is far from common practice but has been done in a few cases. As a better solution, which can be used with a larger isolated breaker, the relatively new nickel-alkali battery with sintered plates can be considered. Where they supply only energy for tripping, this type of battery can be very small and light, compared to the lead-acid type. Sometimes they may be installed complete with charger in the same housing with the relays or in the operator cabinet of an outdoor breaker with considerable reduction in installation cost. This type of battery is not low in price but requires little maintenance and is expected to have long life.

DC trip from a battery (No. 1) is regarded as the one thoroughly reliable method which is universally preferred except where economy is an important consideration. Capacitor trip (No. 2) probably rates second as it can retain all the accuracy and selectivity of dc trip by utilizing the same relays. Where simple overcurrent protection with accurate time delay provides adequate selectivity, either number four or number five may be the best choice. Number three rates last so far as performance is concerned but is dependable and economical where accuracy is not essential.

Differentials recorded by water flow indicating devices can be recorded or put to work by a . . .

Linear Output Flow Meter

by WM. BRUCE MURRAY, Civil Engineering Assoc., Water Dept., Long Beach, Calif.

EDITOR'S NOTE: This article describes a device for indicating water flow by direct readings. The device produces an electrical output directly proportional to incoming raw water flow to a water treatment plant, therefore, besides indicating flow, it can also pulse chemical injection equipment, totalizers, etc.

Much of the detail has not been presented because of space limitations. If additional information is desired by the reader, the editors suggest he write the author directly.

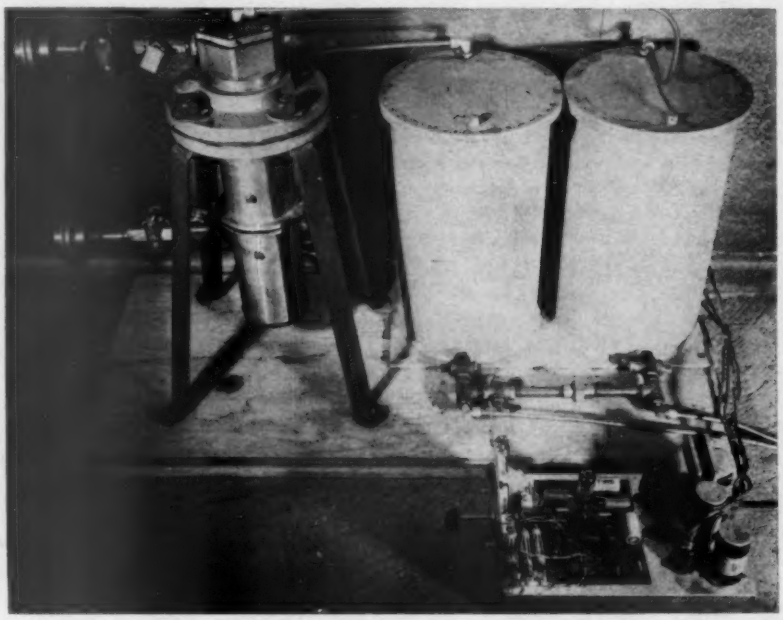
■ A DIFFERENTIAL EXTRACTING FLOW METER, of the type to be described, is indicating flow of raw water entering the Long Beach Water Treatment Plant, Long Beach, Calif. The unit is connected across a 42 inch orifice plate on the raw water inlet line to the plant and besides indicating flow, it is also controlling the feed rate of copper sulfate and chlorine to the raw water.

The designed purpose of this flow indicating device is to meter a differential producing device such as a Venturi tube, orifice plate or flow nozzle and produce an electrical output which is directly proportional to the velocity of the incoming raw water flow. The flow indicating device will:

1. Sense and extract the non-linearity of a differential producing meter in one operation.
2. Detect differential equivalent to 150 inches of mercury within an accuracy of 2 inches of water without range adjustment.
3. Minimize differential surging.
4. Provide instantaneous readings from maximum to minimum scale.
5. Provide an electrical output which can be indicated, recorded and totalized.
6. Maintain an accurate output unaffected by ambient or process temperature changes.

General Description

The flow indicating device essentially consists of a diaphragm which is subject to a force unbalance created by the pressure differential exerted on each face of the diaphragm from the high and low pressure taps of a differential meter. Opposing this force unbalance is a continuously oscillating wire (Figure 2) of a certain designated length, one end of which is fastened to the axis of the diaphragm, normal to its surface, and the other end of which is fastened to a fixed support. A similar wire separate from that attached to the diaphragm but subject to the same environment, is also in continuous oscillation, the frequency of which is made to electrically oppose



DEVICE being used to monitor primary meter on raw water inlet at the Long Beach Water Treatment Plant. The unit indicates changes in flow and produces a linear output to control the rate of copper sulfate and chlorine injection proportional to the flow.

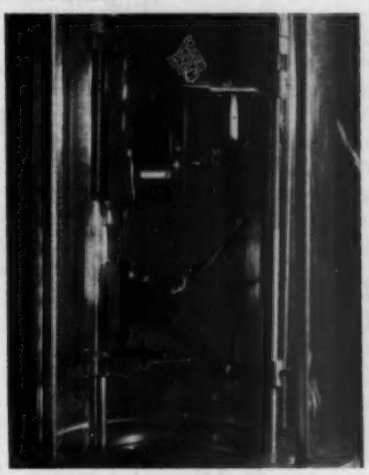
that of the diaphragm-attached wire. This second wire is externally loaded with a variable length adjustment so that its frequency can be made identical to the diaphragm-connected wire at no-flow or static pressure conditions. A pressure differential across the diaphragm sponsored by the flow of raw water into the water treatment plant through the primary metering element increases the tension in the diaphragm-connected wire in the device which increases its frequency of oscillation. The resolved difference between the two wire frequencies is a direct measurement of the raw water flow (velocity). The externally loaded wire establishes an initial operating condition which eliminates the necessity of an external bridge and also provides a means of temperature stabilizing the system.

Sensing Element

The device, illustrated at the bottom left of Figure 3, senses the differential produced by the primary metering element and converts this differential to a mechanical movement represented by the vibration of a wire. Essentially this unit is composed of two receiving reservoirs and a pressure extracting chamber which consists of a flanged cylinder separated into two compartments by a neoprene diaphragm. The upper side of the diaphragm is subject to the force exerted from the high pressure tap of the primary metering element and the lower side of the diaphragm, the force exerted by the low pressure tap. During conditions of flow through the primary meter, the force unbalance across the diaphragm imparts a tension in the wire connected to the diaphragm which is proportional to the force. This wire passes through a thin-walled modified pipe arrangement which establishes a constant distance between the take-up winch and a point intersecting the perimeter and the center line of the pulley. The winch provides a means of initial diaphragm adjustment in which the tension in the wire is equivalent to the mass of the lead weight at no flow or zero differential when the diaphragm is distended. The wire leading from the low pressure chamber which is not connected to the diaphragm, is a reference wire that is subject only to a force provided by the mass of weight hanging from its free end resulting in a fixed wire tension between the vertical axis of the pulley and the micrometer screw. The two electromagnet-electromagnetic pickup supports, besides positioning the wires, contain the electronic components which together with other related equipment provide a means of starting and keeping the wires in vibration. Note that the physical characteristics of the high and low pressure chambers are identical except for the difference in volume and the length adjustment of the reference wire. Once the calibration of the diaphragm-connected wire is completed (initial adjustment at zero differential), the micrometer screw is turned either in or out until a position is obtained with the reference wire in which its frequency of oscillation is exactly equal to the diaphragm-connected wire.

The high and low pressure reservoirs are located intermediate between the pressure extracting unit and the primary meter. It is the purpose of these units to resolve the liquid pressure of the primary meter taps to a gaseous state in order to prevent dampening of the wires and other related equipment. During a condition of operation, the liquid or water will rise in the high and low pressure chambers to an elevation in which the pressure of the compressed nitrogen* will equal the pressure of the applied fluid.

Standard plumbing parts are used throughout the construction of the sensing element. The pressure extracting unit must be made of high grade brass, particularly the electromagnet-electromagnetic pickup supports. Placement of the electromagnet and the electromagnetic pickup must be as indicated in Figure 3 with approximately 2.5 inches O. C. separating each unit. The pulleys must be machined to a very close shaft tolerance in order to prevent vibration and dampening at certain operating frequencies. The weights can be made uniform by constructing each to the same dimensions and balancing their mass with lead shot (± 4 pounds). The flanges on either side of the neoprene gasket should be of metal-inserted Uscolite because of their light weight and electrical insulation qualities. The pressure reservoirs can be composed of standard pipe; however, special consideration should be given to the wall thickness and the plate size since enormous forces are encountered even at the most moderate pressures.



PRESSURE applied to a diaphragm-connected wire increases the tension on the wire and increases its frequency of oscillation.

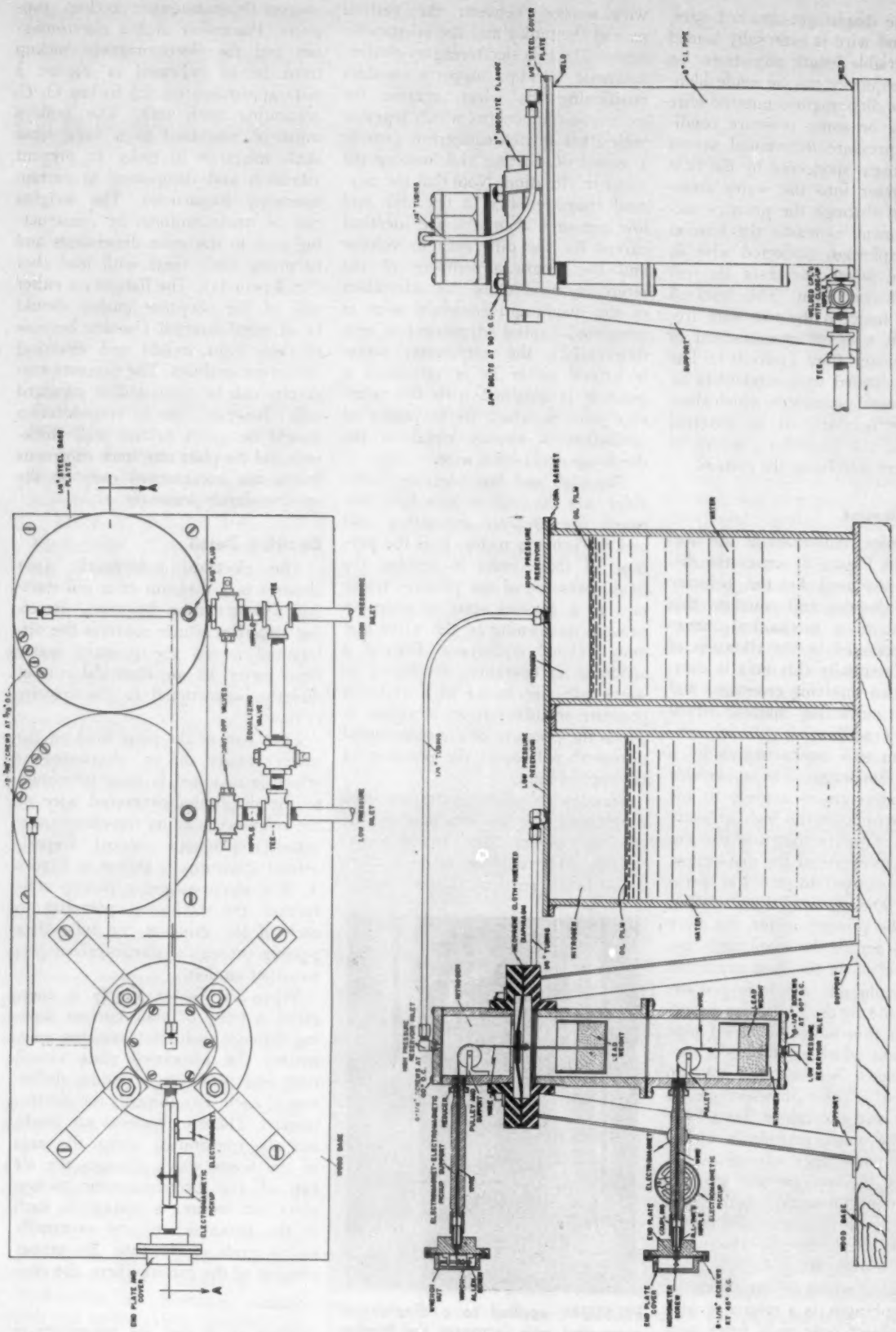
Electrical Detail

The electrical schematic (not shown) is a diagram of a self-starting, self-oscillating frequency detecting amplifier which converts the differential across the primary water flow meter to an electrical output directly proportional to the velocity of flow.

Each half of the plate load on the tube consists of an electromagnet which is mounted in close proximity to the diaphragm-connected wire or the reference wire on the electromagnet-electromagnetic support. Experimental apparatus is shown in Figure 4. The electromagnetic pickup coils furnish the excitation potential to each of the grids of the tube after passing through a transistorized preamplifier section.

When the power supply is energized, a pulse of plate current flowing through each electromagnet magnetizes the associated plate circuit core and produces a minute deflection of each wire towards the electromagnet. These movements are mechanically transmitted along the axis of the wires which changes the air gap of the electromagnetic pickup coils and induces a voltage in each of the preamplifiers and eventually to the grids of the tube. By proper phasing of the preamplifiers, the con-

*Nitrogen gas is inert and non-corrosive to metallic, rubber and plastic parts. Its most important feature is that it will not combine or enter in solution with water.



THREE DIMENSION view and section of differential extracting flow device.

ditions of self-sustaining oscillations are fulfilled.

The coupling between each plate and grid of the tube is through the mechanical movement of the wires and not through any direct magnetic coupling between the plate and grid electromagnets. Stopping of the mechanical vibration of the wires causes the tube to cease oscillation.

A portion of the energy from each plate circuit is limited and clipped by the diode sections and resistors. This action is necessary to produce a uniform output signal throughout the frequency range since the intensity of wire oscillation varies as the square of the amplitude. Since there are 1.5 volt cells in the diode ground returns, the output of the clippers cannot exceed 3 volts peak to peak over wide ranges of signal input. Each output from the clipper section is connected to the bases of the unbiased transistors which produces square waves across the variable load resistors.**

Positive pulses appearing across the bases of transistors effectively cut off these transistors so that the potential of the RC network becomes that of the supply. The capacitors are then able to discharge through the resistors, diodes and through the modified bridge to the D. C. output terminals. When a negative cycle of signals reverses the potential on the bases of transistors, the voltage of the R. C. network falls to a low value and the capacitors discharge to ground through the diodes.

The long time constant of a meter movement placed across the D. C. output terminals integrates the algebraic sum of the uni-directional charging pulses to provide a steady meter reading which is a linear function of the input signal frequencies according to the equation:

$$i_M = FCE_o$$

Since capacity **C** and $\mathbf{E_o}$ (amplitude of the charging current pulse) are fixed by choice of capacity and the action of the limiting circuit, i_m becomes a function of frequency only.

The signals supplied by the diaphragm connected wire and the reference wire are entirely separate except for the common power supply and the frequency comparison circuit of the output.

**Minor, W. H., *The Transistor in Simple Circuits*, Radio and Television News, 1952.

WIRE OSCILLATION is made self-sustaining through proper phasing of the preamplifiers.

A loudspeaker provides a convenient means of initially calibrating the flow metering device. The audio output switch is closed on the loudspeaker circuit which cuts out the variable output resistance and forces the square wave signals to appear across the secondary of the plate transformer. With the sensing device disconnected from the primary meter (input terminals closed), the length of the reference wire is varied with the micrometer screw until a position is obtained in which the frequencies appearing across the loudspeaker are identical and no beat note can be detected. This is a rough approximation. Greater accuracy can be obtained by using an oscilloscope in conjunction with an electronic switch and superimposing one signal over the other during the reference wire adjustment.

Prior to actual operation (assuming the above correction has been made), the audio-output switch should be returned to its initial position (output) and a 50 microampere D. C. meter connected across the output terminals. The meter output should read zero. If the meter fails to read zero, it can be corrected by adjusting output resistances on one or both of the resistors.

The power supply is full wave rectified and heavily filtered to reduce ripple. Voltage regulation is not necessary since the device can tolerate a voltage change of ± 50 volts without changing frequency. Since it is very important that both sections of the circuit be stabilized, a voltage divider arrangement was employed to furnish the plate supply voltage to the tube and the collector supply to the transistors.

The electronic control amplifier contains four controls: two function switches (audio-output switch and a range selecting switch) and two calibration potentiometers. The range selecting switch, when used in conjunction with the calibration potentiometers, provides full scale meter deflection at any of the three positions (0—10, 0—100 and 0—1000).

Rate or Totalizing Control

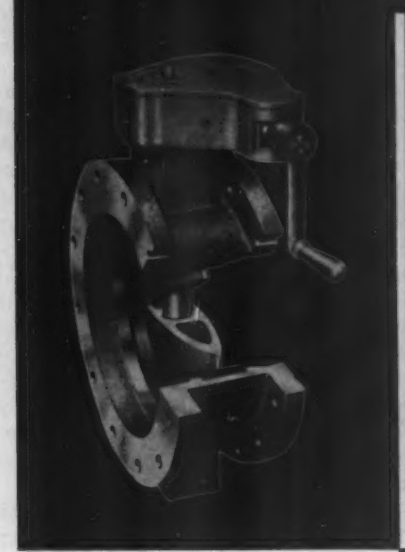
In addition to an instantaneous or indicated value of frequency (or velocity), another circuit can be added to provide a means of obtaining a rate output directly proportional to the strength of the applied D. C. signal.

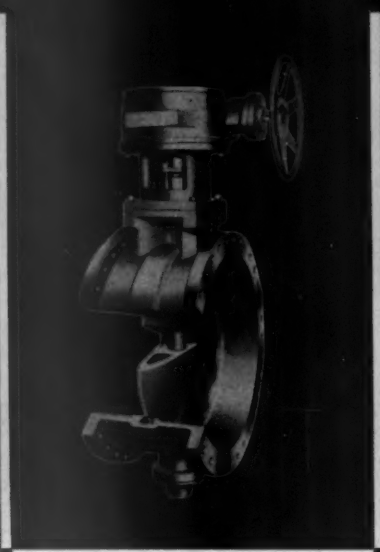
The basic element is an electromagnet which consists of a coil wound around an iron pole piece. A steady A. C. voltage (6.3 volts from the filament supply) is impressed on the coil and the resultant alternating current in the electromagnet coil produces an alternating magnetic field across the gap of the pole piece. The electromagnet (being horseshoe-shaped) is mounted against the microammeter case and induces the magnetic field (A. C.) on the steady magnetic field of the permanent magnet which is part of the meter movement.

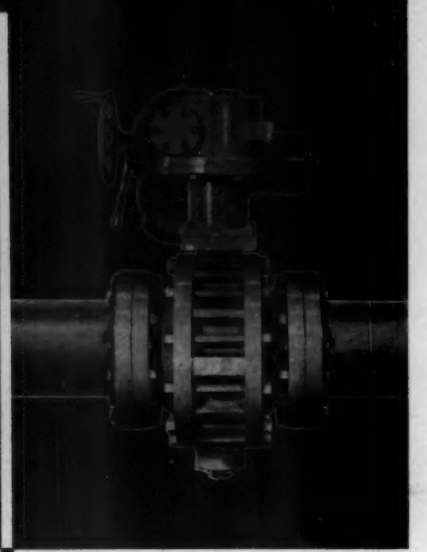
A small D. C. current applied to the terminals of the microammeter (proportional to the velocity of water flowing through the primary meter) deflects the moving coil and induces a small A. C. voltage in the coil. A phase change occurs between the initial zero-center position and the maximum coil movement of 50 microamperes, the value of which is equivalent to the strength of the applied D. C. signal. The induced A. C. voltage is applied to a two-stage resistance coupled vacuum tube amplifier, the output of which controls the grid of a thyratron. Normally a thyratron, once it has ignited, will operate indefinitely until the voltage source (plate supply) is removed. However, by proper phasing at the grid signal, the grid potential can be made to exceed the critical bias at any point and thus control the conductivity of a thyratron for any portion of a cycle. The D. C. motor located in the cathode of the thyratron can therefore be controlled smoothly by simply changing the phase of the A. C. signal applied to its grid.

A cam-operated microswitch mounted on the shaft of the motor provides a means of obtaining a rate measurement proportional to the applied D. C. signal which can be used to pulse chemical injection equipment, totalizers, etc.

Now! PRATT STANDARD RUBBER SEAT VALVES FROM VACUUM TO 250 psi







150 psi Standard Valve Flanged or Monoflange

This Henry Pratt valve is loaded with extra values . . . the most *rugged construction* available . . . lower costs due to complete standardization . . . and economical *space savings* thru new narrow face-to-face dimensions in classes up to 125 psi . . . *new sidewinder operator* with manual, cylinder and motor types.

Highly versatile—available in 2 flange or monoflange types, with floor stand or extension bonnets, and completely sealed operators for buried service.

For AWWA classes 25-8 thru *125-16* in sizes 4″ thru 20″.

Write for Bulletin 6-B.

50 and 125 psi Standard Valves with adjustable seat

For the first time, 50 psi Standard Valves are available with economical narrow face-to-face dimensions thru the full 50-16 classification. The 125 psi Standard Valves in wide face-to-face offer traditional Pratt ruggedness in classes 50-8 thru 125-16. In all classes the valve seats are factory adjusted around their perimeter for the most precise fitting of disc to seat, a feature that offers:

Easier operation—with a precisely fitted seat.

Longer Life—accurate control of disc-seat interference provides tightness without wear.

Bubble-tight operation up to 150 psi.

Easy field adjustment . . . seats can be adjusted or even replaced without dismantling the valve or removing it from the line . . . and the seat fitting will be factory accurate.

Sizes 24″ thru 72″.

Described in Bulletin 6-B.

Pratt Rubber Seat Ball Valve for 150 and 250 psi

Resilient seating has now been applied to ball valves—putting the time-proved advantages of this seat to work at higher pressures and velocities than ever attained before.

The Henry Pratt Ball Valve offers bubble tight performance for ball or cone valve applications plus these definite advantages: *less weight, smaller size, lower operating torques* than similar valves . . . and *no more pressure drop than equivalent length of pipe.* The rubber seat will not bind or stick and compensates for line distortion. One man operation against full line pressure.

Complete line of operators and accessories. Ideal for buried service with enclosed operator. Sizes 10″ thru 48″.

Write for Bulletin BA-1-B.

Creative Engineering for Fluid Systems

HENRY PRATT COMPANY
319 West Van Buren Street · Chicago 7, Illinois
Representatives in Principal Cities

HENRY PRATT®

One Source for a Complete Line of

WATER and SEWAGE WORKS EQUIPMENT

Vertical sewage pump

Centrifugal Pumps — Vertical or horizontal, for sewage and activated sludge.

Vertical Turbine Pumps — Wide range of sizes.

Blowers — For sewage aeration.

Rotary Vacuum Pumps—For use with vacuum filters in dewatering sludge.

Rotary Compressors — For compressing digester gas.

Dryers — For sludge dewatering.

Vibrating Screens — For removing solids from liquids; also in fertilizer manufacture.

Sifters — For grading fertilizer.

Roller Mills — For grinding fertilizer.

Motors and Control — For all drives over 1 hp.

Power Equipment — Steam turbines, condensers, pumps, water conditioning.

Electrical Equipment — Transformers, switchgear, circuit breakers, unit substations, generators, voltage regulators.

Engines — Diesel, gasoline and LP gas. Also generating sets.

Tractors — Wheel, track-type and utility. Also graders and earth moving equipment.

Lift Trucks — For quick and easy handling of materials.

Valves — Butterfly and rotary types for water and Sewage Works applications.

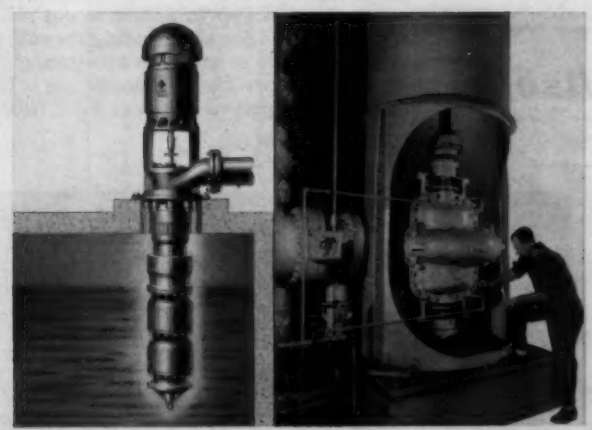
Car Shakers — For unloading coal for power plants.

Lime Treatment Equipment — For water softening plants.

Compacting Equipment — For fertilizer plants.

Here's a new motor development that can save you money. This open-type *Super-Seal* motor ran for hundreds of hours under water . . . in a 4% brine solution. If you have had trouble with ordinary open motors and are considering splash-proof or enclosed types get in touch with Allis-Chalmers and ask about *Super-Seal* motors.

The answer to all your needs



Vertical pumps are proving to be the answer to many waterworks problems . . . space . . . flooding. Allis-Chalmers offers a choice of pumps, depending upon application. Type S centrifugal pumps are used in many waterworks, both large and small. Vertical turbine pumps (right) are available for capacities up to 8000 gpm, heads to 400 ft or more.

There's good reason why Allis-Chalmers is recognized as *the* leader in the public works industry. Nowhere else in the world will you find the convenience of a single source for so much public works equipment.

One look at this long list reveals that Allis-Chalmers can help you solve any problem, whether your operation is a sewage plant, water works, municipal power plant, street and highway construction, or other projects.

Imagine a line of pump sizes ranging in capacities of a few gallons per minute to huge 300,000-gpm units. And what a reputation they have. Not one centrifugal pump has ever failed to meet its guaranteed efficiency.

Pumps are only a part of the extensive line of equipment manufactured by Allis-Chalmers. There are motors of every type for operating every size pump, and control for every motor. There is also every type of power generating and power distributing equipment helping municipalities all over the world to grow and prosper.

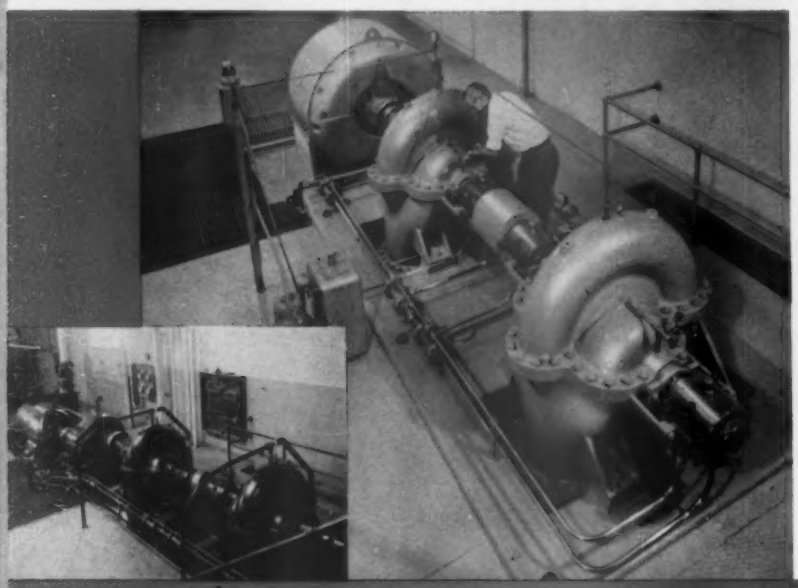
Allis-Chalmers will help you analyze your problem and select the proper equipment for your needs.

ALLIS-CHALMERS

Take advantage of Allis-Chalmers public works experience. Call your nearby A-C office, or write Allis-Chalmers, Milwaukee 1, Wisconsin

25 C 6607H

WATER WORKS EQUIPMENT....



Why you get MORE pump value when you specify Allis-Chalmers

You draw on Allis-Chalmers wide experience in supplying pumps for public works . . . for expert engineering and application help. You get pumps made of best-quality materials, of heavy duty construction, of high-efficiency design. Allis-Chalmers is the only company that offers you "one source" responsibility, with a complete unit—pump, motor and control—all built to work together—all built by A-C.

This installation in Harrisburg, Pa., shows one of the reasons so many municipalities choose Allis-Chalmers Type S pumps. The insert photo shows the installation as it was made in 1922. During the intervening years cost of purchased power has decreased in relation to other power costs and maintenance costs on the old turbines and boiler system greatly increased. *The pumps, however retained their efficiency and low maintenance.* Instead of buying new units, the drives only were changed . . . from steam turbines to Allis-Chalmers electric motors. They are now good for many more years of low cost operation.

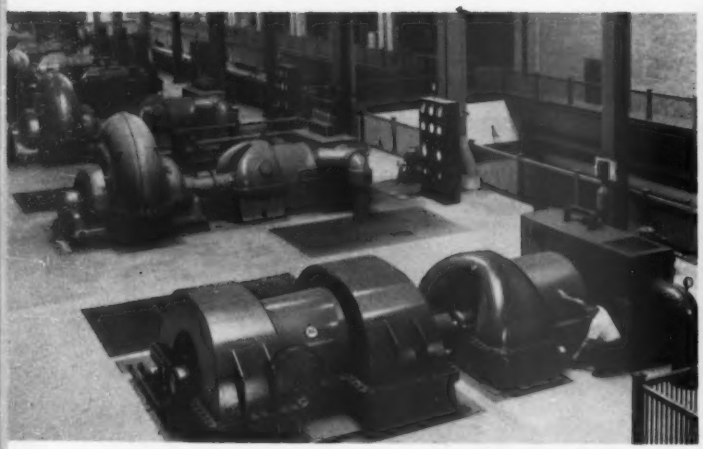
Allis-Chalmers helps you . . .

PUT WASTE TO WORK

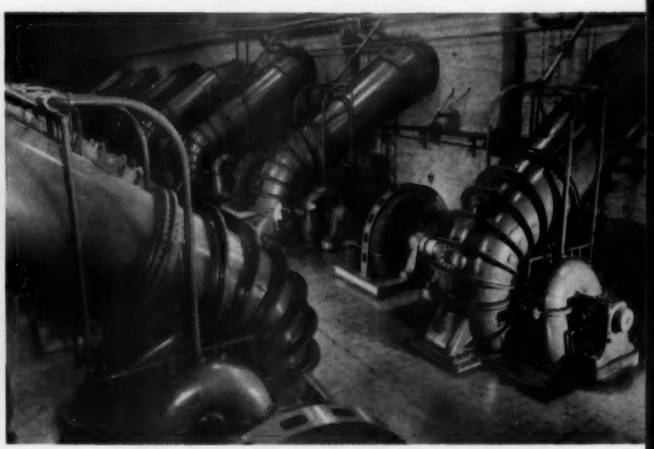
Plan sewage disposal system to help pay for itself

Expansion is the goal of every progressive community, and with expansion comes rising costs in added sewage plant facilities and equipment. Allis-Chalmers experience in public works systems can help you with a profitable expansion or modernization program.

The sludge flow sheet shows the variety of Allis-Chalmers (shaded) equipment used to extract valuable by-products, and how many communities are applying them to cut plant operating costs. Some are finding the sale of fertilizer defrays as much as two-thirds the cost of plant operation. Digester gas is being used to supply power and light needs.



At the Metropolitan Sanitary District of Greater Chicago, West-Southwest sewage treatment plant, this 200,000 cfm, 8½ psig, four-stage axial is used as a base load machine. The centrifugals in the background provide the balance of the capacity needed, and meet load swings.

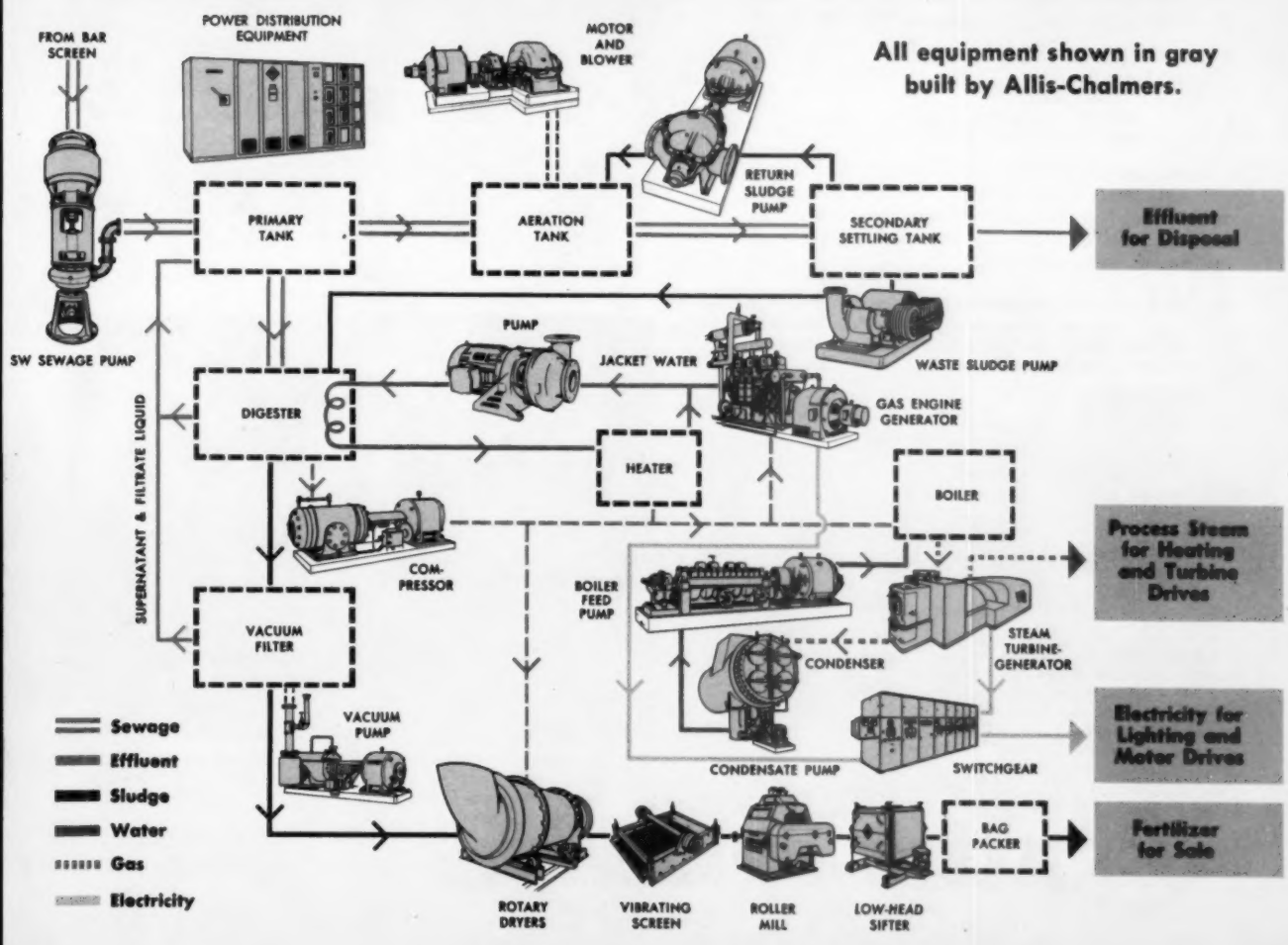


Twelve 72-inch centrifugal pumps at the Racine Ave. Station, Sanitary District of Chicago. They range in capacity from 375 to 500 cfs. They are driven by Allis-Chalmers synchronous motors, ranging in size from 1000 to 1750 hp.

City of Elyria, Ohio, uses four 12 x 10 inch Type S double suction pumps driven by Allis-Chalmers squirrel cage motors. Three are rated 3500 gpm and one at 2800 gpm, against 330 and 320 ft heads.

City of West Allis, Wis., pumping station is equipped with Allis-Chalmers vertical Type S pumps, *Rato-Valves* and rubber-seated butterfly valves.

Colorado River Municipal Water District station has five Type S pumps driven by Allis-Chalmers squirrel cage motors and controlled by the Allis-Chalmers metal-enclosed units shown on the right.



ELECTRIC POWER EQUIPMENT

• Generation
• Distribution
• Control

Allis-Chalmers can supply a major percentage of all power generation, and electrical control and distribution equipment for public works. Included in the power generation line are steam turbine-generator units, surface condensers, condenser and boiler feed pumps, water conditioning service and equipment.

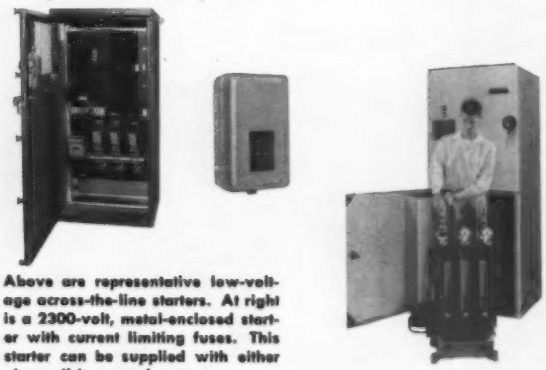
The range of electrical products includes all types and sizes of motors from 1 to 100,000 hp and up, and control to suit every application.

Allis-Chalmers indoor and outdoor high and low voltage switchgear provides maximum protection and flexible control of power distribution circuits. All units are metal enclosed, factory built, so they need only be bolted in place and lines connected. Switchboards are custom built to fill your needs.

A-C builds a complete line of power and distribution transformers. Most sizes can be cooled with either oil or *Chlorextol* non-inflammable liquid, or they can be of the air-cooled type.

Load center, single circuit and multi-circuit unit substations are built in standard ratings to meet every application. They are completely factory built and can be installed adjacent to equipment being served.

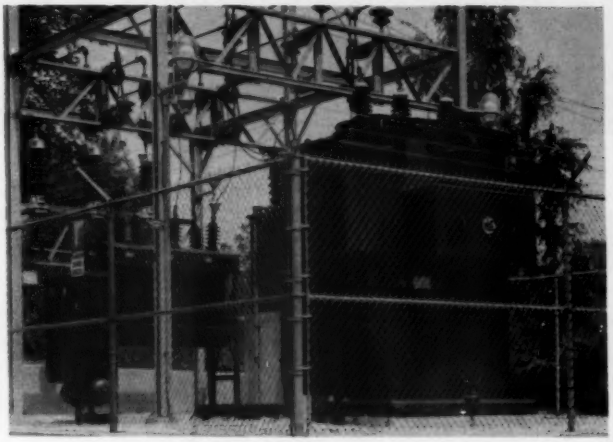
Allis-Chalmers manufactures a complete line of water-works and sewage plant control, including low and high voltage equipment, dc control, and special control systems to meet specific needs.



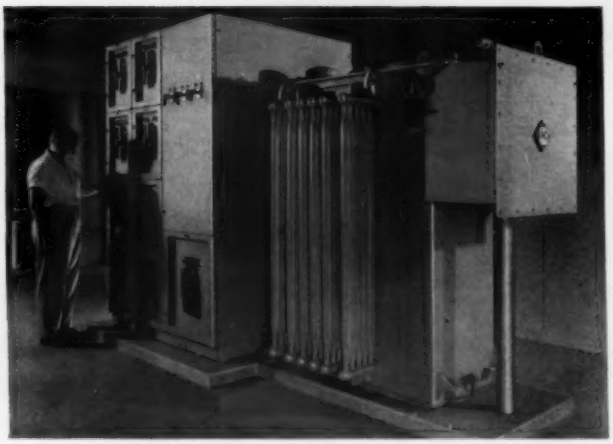
Above are representative low-voltage across-the-line starters. At right is a 2300-volt, metal-enclosed starter with current limiting fuses. This starter can be supplied with either air or oil immersed contactor.

Chlorextol is an Allis-Chalmers trademark.

Allis-Chalmers 5000-kw, 3600-rpm WA-Series steam turbine-generator unit with Allis-Chalmers switchgear in background.



Allis-Chalmers out-door substation protects and controls the electrical power supply for a pumping station.

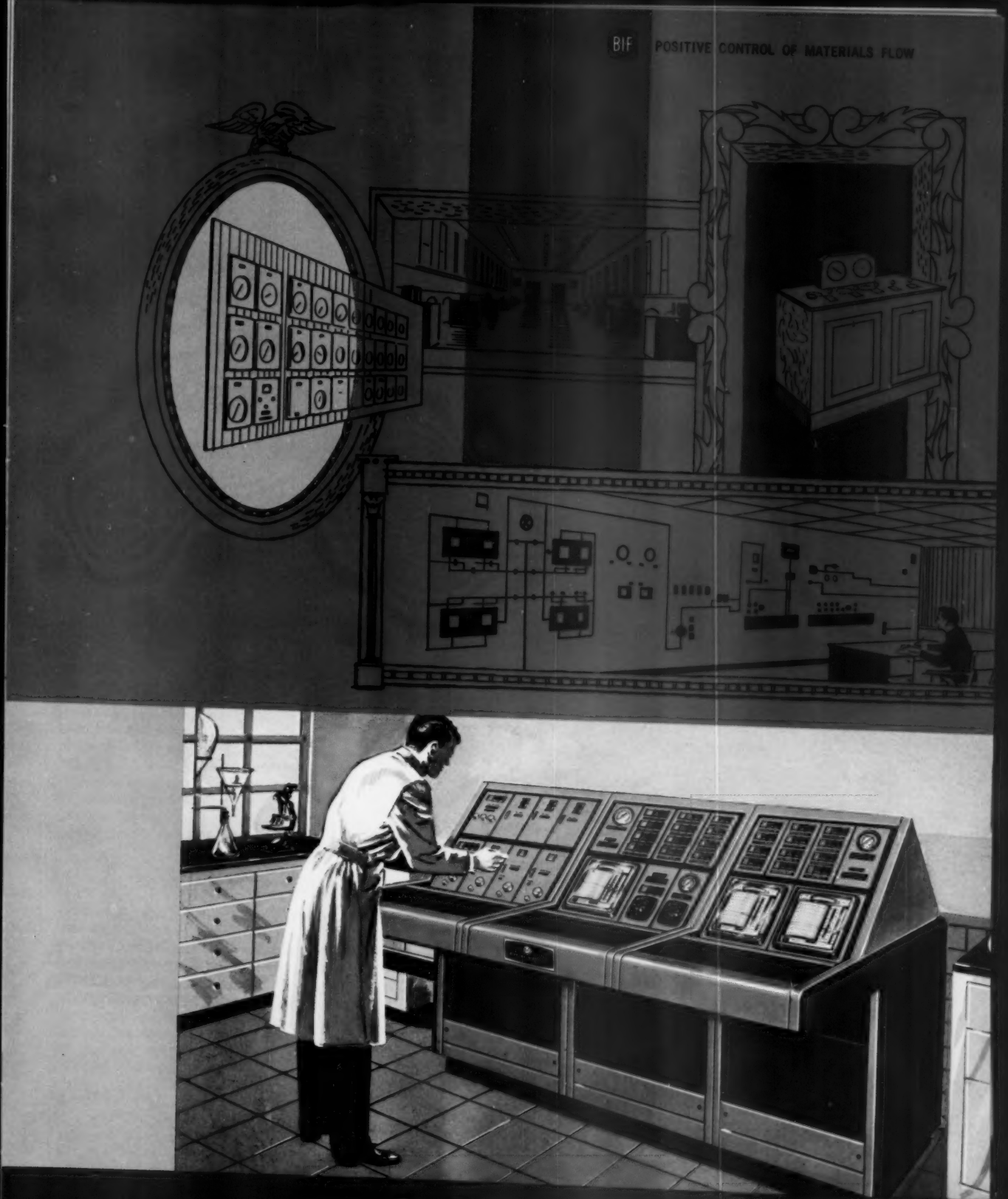


Load center unit substation in a Midwest plant. With this factory-assembled unit you get power right where you want it . . . without long runs of secondary wiring.

ALLIS-CHALMERS

Take advantage of Allis-Chalmers public works experience. Call your nearby A-C office, or write Allis-Chalmers, Milwaukee 1, Wisconsin.

LITHO IN USA

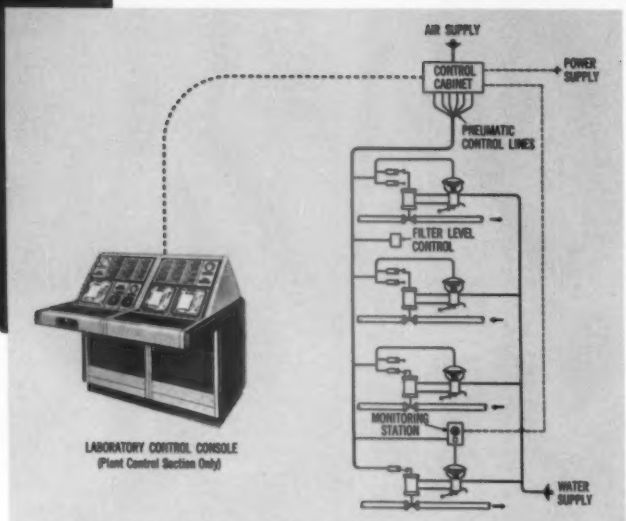


B·I·F Laboratory Control

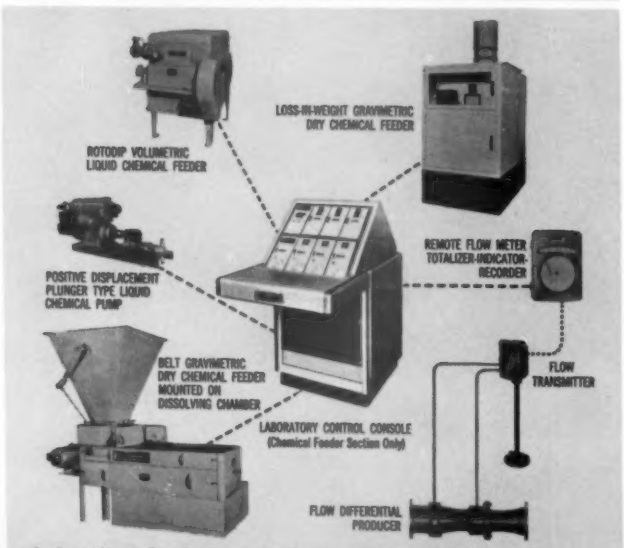
w, advanced concept in water
ment plant design and control

B-I-F LABORATORY

The entire filtration and treatment process under the direct control of only one qualified man . . . the plant chemist or chief operator!



Laboratory Control . . . filter control console with schematic diagram of automatic backwash.


ROTODIP VOLUMETRIC LIQUID CHEMICAL FEEDER
LOSS-IN-WEIGHT GRAVIMETRIC DRY CHEMICAL FEEDER
POSITIVE DISPLACEMENT PLUNGER TYPE LIQUID CHEMICAL PUMP
REMOTE FLOW METER TOTALIZER-INDICATOR-RECORDER
BELT GRAVIMETRIC DRY CHEMICAL FEEDER MOUNTED ON DISSOLVING CHAMBER
FLOW TRANSMITTER
LABORATORY CONTROL CONSOLE
(Chemical Feeder Section Only)
FLOW DIFFERENTIAL PRODUCER

Laboratory Control . . . typical arrangements with chemical feeders paced by flow.

FILTRATION PROCESS

More Efficient Filtration — Automatic backwash control increases reliability of operation . . . permits initiation of manual or automatic backwash program from laboratory console . . . assures high quality effluent. Operations recorder stores all information relative to filter performance in concise, visual form for future reference, eliminating multiple chart changing and storage problems . . . monitors all operations and instantly signals any terminal or abnormal condition.

Saves Space and Taxpayers' Dollars — Centralized control eliminates initial cost and maintenance of the filter housing structure, of individual filter operating stations and allied instrumentation. System reduces damage to beds and resulting downtime . . . assures more productive man-hours.

CHEMICAL TREATMENT

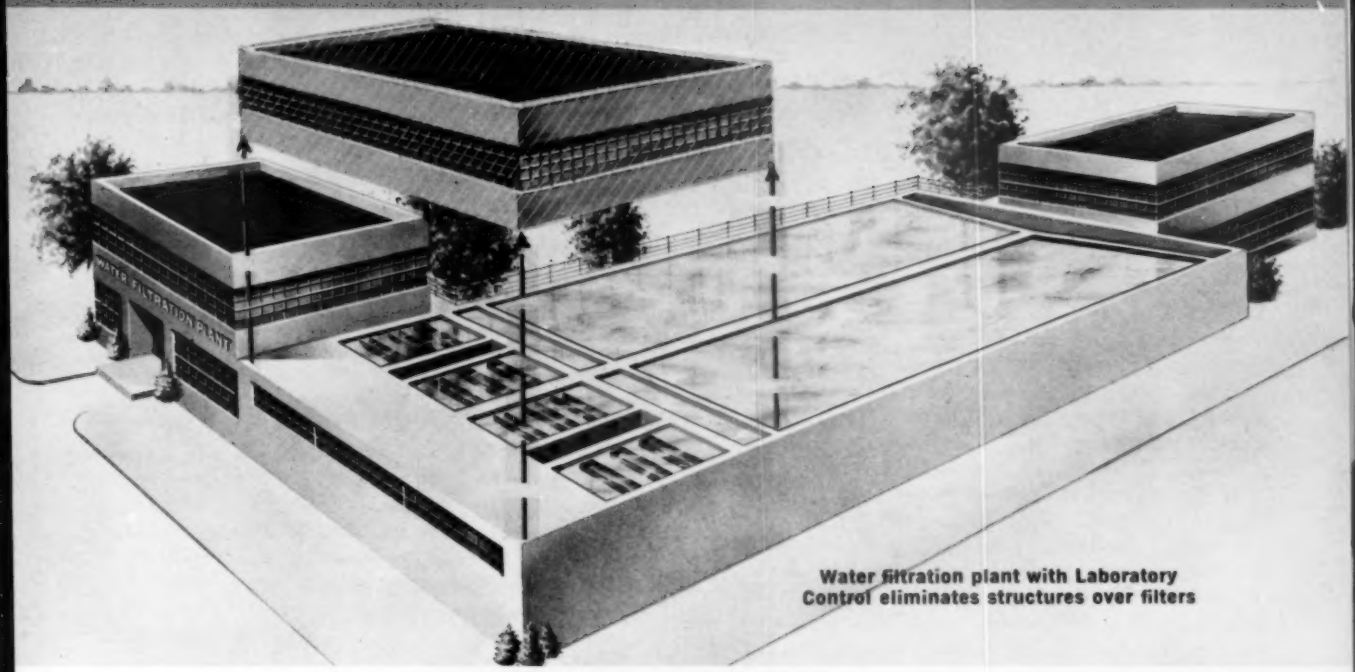
Key-Man Supervision and Control — Chemist or plant operator . . . from central console or laboratory . . . easily controls quantity of filtered water and exact chemical dosages for treatment. Monitoring lights or alarms instantly advise of filter conditions . . . over or under feeding of chemicals, empty hoppers, etc. . . . enabling key-man to make immediate, corrective adjustments. Integrating totalizers provide accurate accounting of quantity of water treated and exact amount of chemicals fed during operating period.

More Effective Operation at Lower Cost — Chemical feeders are remotely located for straight-line process flow (see diagram) which protects floc, improves settling and provides longer filter runs. Remote location of feeders reduces initial plant cost by eliminating need for expensive housing structures . . . reduces maintenance cost by removing chemical dust problem from office and laboratory.

CONTROL

IMPROVED PLANT OPERATION!
INCREASED RELIABILITY!
LOWER INITIAL PLANT COST!
REDUCED OPERATING COST!

- Provides instant fingertip control over plant throughput, chemical additions, and filter backwash . . . from a single console in laboratory.
- Simplifies and improves process supervision . . . releases manpower for more productive assignments.
- Assures filtration efficiency — centralized backwash control automatically initiates washing . . . eliminates over or under washing and upset filter beds.
- Reduces overall plant construction costs 15% to 20% by eliminating structures over filters.

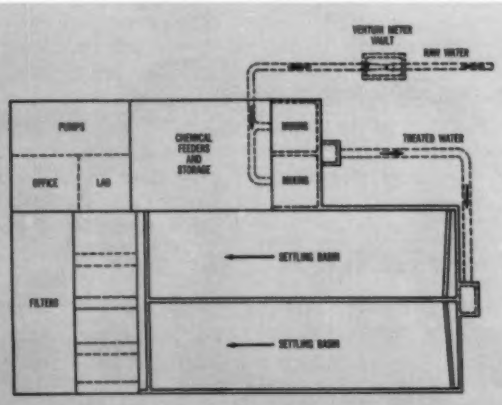


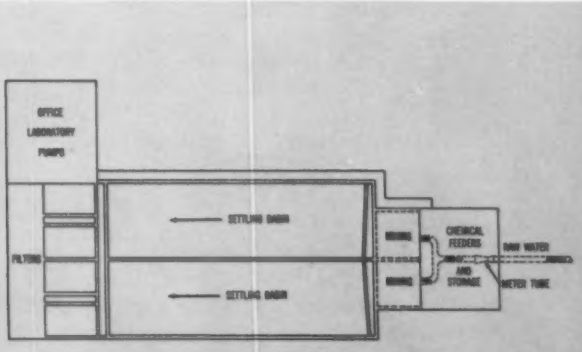
Water filtration plant with Laboratory Control eliminates structures over filters

FACILITIES ARRANGEMENTS

CONVENTIONAL DESIGN: requires costly structures to protect operators from the weather and to house filters and individual filter operating tables with associated recording-controlling instruments.

LABORATORY CONTROL: all operating controls centralized in **one** compact console in the laboratory. The plant is designed for streamlined flow and maximum process efficiency at minimum structural cost.





FOR LIFE-OF-BOND PERFORMANCE

Make your new or expanded water works system "pay off"! Pay only once for new or expanded water treatment facilities. Don't risk plant obsolescence or equipment replacement.

If you want reliable life-of-bond performance, specify B-I-F equipment . . . the most comprehensive, proven line of water works equipment. No other company's reputation is supported by so many successful municipal installations.

The B-I-F product line was developed expressly for the water works industry. Products are system-compatible, extremely durable and completely reliable. Only B-I-F provides this assurance of life-of-bond performance.

METERS AND CONTROLS Complete line of Primary Metering Elements: Venturi Tubes and Nozzles; Dall Flow Tubes; Data Transmission Telemeters for Flow, Pressure, Temperature, Level, Position and Electrical Quantities; Velocity-type Meters.

FEEDERS AND WEIGHERS Volumetric, Belt Gravimetric and Loss-in-Weight Feeders for the complete range of Dry Materials and Liquids required for Water Treatment; Chlorine Gas Feeders.

VALVES Butterfly Valves and Operators for Low and High Pressure Applications.

SYSTEMS Supervisory Control Systems; Filters and Filter Control Systems; Volumetric and Gravimetric Systems for Automatic Blending, Feeding, Treating, Sampling.

Request complete data on any product or system. Write **B-I-F Industries, Inc., 345 Harris Avenue, Providence 1, Rhode Island.**

B-I-F *Industries*

BUILDERS-PROVIDENCE • PROPORTIONEERS • OMEGA

METERS • FEEDERS • CONTROLS / CONTINUOUS PROCESS ENGINEERING

Butterfly Valve Actuators
Part I—Manual Operators

by ABDON J. BRAZAITIS
Application Engr.
Henry Pratt Co.
Chicago, Illinois

Basic Manual Operator Types

■ The most common type and most widely used manual operator for butterfly valves is the totally enclosed worm gear reducer. This unit consists of a worm of hardened high alloy steel driving a worm gear usually made of gear type bronze. The entire internal is packed with grease for lubrication and rarely does the unit require repacking. "O" ring seals or similar seals prevent the lubricant from leaking from the gear case. These gear reducers are suitable for normal outdoor service. Many of the worm gear units available today are also equipped with anti-friction bearings on the worm shaft and worm gear hub, to absorb thrust and reaction forces, thus keeping friction losses at a minimum. One of the recent advances in the worm gear unit, designed for butterfly valves, has been to provide a worm gear made up of two pieces. The outer rim of the gear has teeth of gear bronze and is bolted to the hub of high strength steel. This hub of steel allows the hub to be splined internally to receive the butterfly valve shaft, as shown in Fig. 1. Note that the butterfly shaft has a coupling, shrunk fit and keyed, with external splines. When the worm gear unit is mounted on the butterfly valve shaft this splined connection allows fast coupling, no play, and high torque capacity. Stop settings for valve travel are usually located in the internals of the gear case and are factory set and ordinarily do not require field adjustments of any kind. An indicator arrow connected to the gear hub gives an accurate index of valve position. A typical worm gear unit is the handwheel type shown in Figure 2.

A second type of manual operator for butterfly valves is the screw, consisting of a screw and lever arrangement replacing the worm gear set. Two types of screw and lever operators are available as shown in Figures 3, 3A, and 4. The operator shown in Figure 3A is simply a traveling nut unit with the nut engaged with the lever by means of the roller bearings. The lever usually has double arms to prevent the nut from turning and is slotted to allow for the change in effective lever length as the nut travels along the screw. The operator shown in Figure 4 is more widely used and consists of a traveling nut and connects to the lever by means of an intermediate link thereby eliminating the need for slotting of the lever. The geometry of this linkage has another effect which is useful in certain valve applications. As the valve approaches the closed position, the increment of travel of the nut, to effect an increment of travel of the lever, increases rapidly, and in effect, "slows down" the operator as the valve moves closed. This is a useful feature on butterfly valves used in distribution mains in that the valve is substantially closed during the first half of the closing operation while at the same time sufficient area of valve is left open to dissipate the over-pressure created by shock wave, until the amplitude of these over-pressures reaches a safe level. The screw usually is an Acme type thread chosen to yield high strength and minimum friction and wear. Use of this type operator is increasing and especially in the higher torque applications where the screw, lever and intermediate link arrangement has considerable merit in performance and economy.

A variation of the screw and lever arrangement should be mentioned. This variation substitutes a ball-screw type arrangement for the Acme screw and nut and thereby affects a considerable increase in overall efficiency and in certain cases eliminates the need for additive gearing quite often required if a worm gear or Acme screw and lever arrangement is used. The ball screw set itself is not "self-locking" but there are devices available to provide this function. This is essential in a butterfly valve operator due to the tendency of the valve to close when moved slightly off the full open position. In general, the use of the ball-screw is usually governed by the economics of any given application and usually bears consideration at higher torque outputs.

The manual torque applied to the input shaft of a gear, or screw, unit is usually transmitted through a handwheel, chainwheel or a standard AWWA square nut. The handwheel unit is used where pipelines are readily accessible and is the most commonly used. The chainwheel drive is used where the butterfly valve is located in overhead piping. The valve is operated through a chainfall from the deck below. If the line is considerably above operating grade, a special indicator of larger proportions may be desirable, especially for throttling applications when chainwheel operated valves are used. The AWWA nut operator is principally used for valves installed in a vault or completely buried, with a tee wrench being used to open and close the valve. In the case of the buried unit, it is sometimes useful to furnish a valve box with a built-in valve position indicator. A typical illustration of a buried valve is shown in Figure 5. Other variations of applying input torque to the operator will be mentioned in subsequent sections.

Commonly Used Additions to Manual Operators

One of the additions to a manual unit used quite often is a "locking" device on the input shaft of the unit. This usually is a simple clamp or ratchet pawl arrangement and in the industry today the term "locking" is still applied. If a true "lock" is required, the best and most common is still the chain and padlock arrangement with the chain circling one of the handwheel

spokes. As mentioned previously the worm gear and Acme screw units are inherently "self locking" because of the locking angle cut on the gear teeth or screw thread.

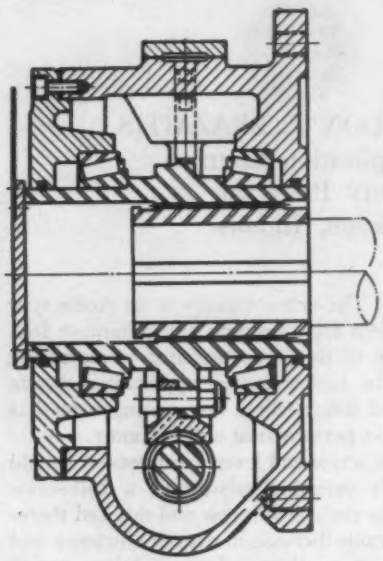


Fig. 1. NOTE HUB of steel which allows the hub to be splined internally to receive the butterfly valve shaft.

Quite often the torque output of a gear or screw unit is of such a high value that additional mechanical advantage must be added to the unit if the input torque is to be kept to a minimum. For this purpose an additional gear case is added to the main gear housing at the input shaft. This gear case contains a spur gear set with a ratio such that the required mechanical advantage is obtained. Another application for the spur gear set, apart from mechanical advantage, would be the "slowing down" of the operator by simply requiring more turns of the handwheel to close the valve. An illustration of a typical spur gear attachment is shown in Figure 6. Adding a spur gear set for the purposes of increasing operating torque should not be carried to extremes. When a valve has been fully closed, the stops in the gear housing stop all motion. An over-zealous valve operator may want to "wedge the old valve tight" and cause serious wear or galling of the screw or gear on subsequent operations.

A bevel gear attachment on a gear case serves the same function as the spur gear case attachment but in addition it changes the relative positions of the input shaft and the worm or screw. Where the spur input shaft still is parallel with the main worm gear shaft the bevel gear attachment input shaft is at 90° to input of the worm gear shaft as illustrated in Figure 6. This attachment is particularly useful for valves located in valve vaults. The valve can be installed with the valve shaft in a vertical position and the operating nut would be in a vertical position for operation from a street box. The vault size required therefore need only clear the valve flanges. With the spur gear attachment, the valve shaft would have to be horizontal in order to have the AWWA nut in a vertical position. In general the bevel gear addition is useful for difficult "laying in" applications in addition to being useful to obtain mechanical advantage.

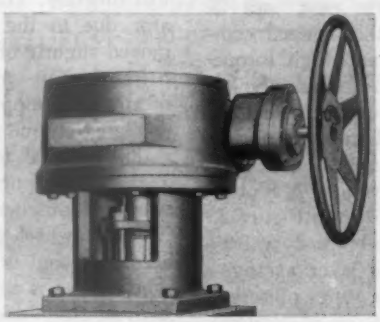


Fig. 2. A HANDWHEEL type typical of worm gear units.

Some more rare additions to manual operators might be mentioned briefly. If it is advantageous to manually operate two valves in unison with one handwheel a simple method is to have one gear reducer with an input shaft on both ends of the worm. The second valve operator shaft is then coupled to this extra shaft on the first gear reducer. Operating the handwheel on the first unit will operate both valves in unison and in phase or 90° out of phase as required. A second method of operating both valves with one handwheel is the use of a mitre box drive as shown in Figure 7. In general, for special variations of this type it is best to consult with your valve manufacturers engineers for a recommendation.

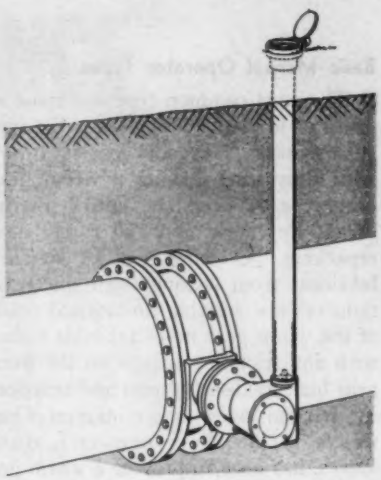


Fig. 5. TYPICAL ILLUSTRATION of a buried valve.

Operator Modifications—Special Applications

For distribution mains, the butterfly valve is suitable for completely buried lines. However, certain modifications to the gear unit are required. The indicator arrow is removed and a stationary cover plate seals off the gear unit. The cover on the input shaft of the gear unit, whether it

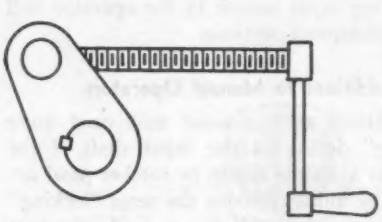


Fig. 3. ONE TYPE of screw and lever operator.

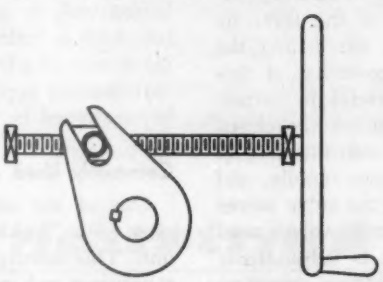


Fig. 3A. A TRAVELING nut unit with the nut engaged with the lever by means of the roller bearings.

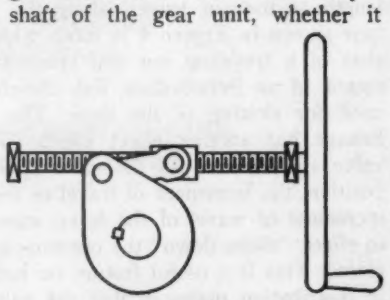


Fig. 4. A WIDELY USED operator consisting of a traveling nut and connecting to the lever by means of an intermediate link.

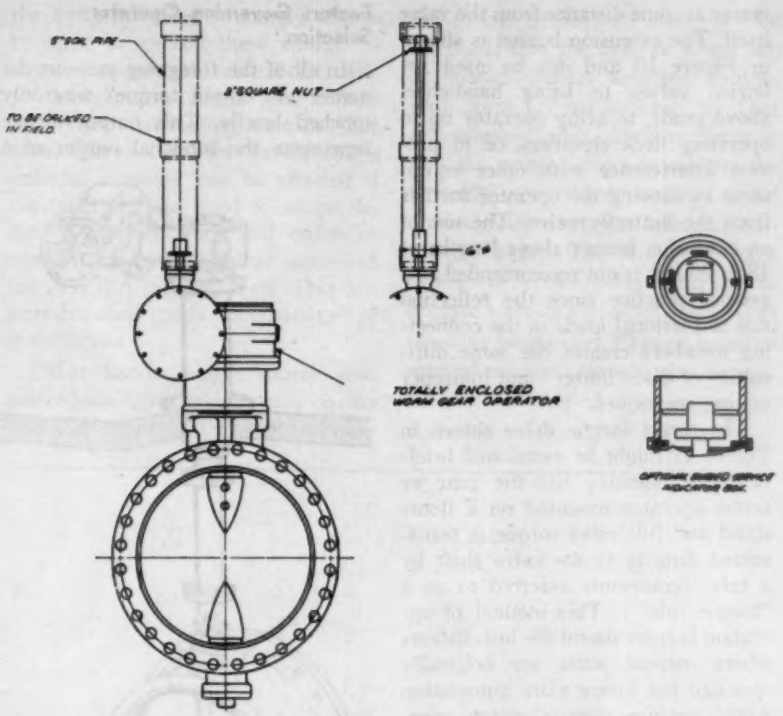


Fig. 6. A TYPICAL spur gear attachment.

be standard or with a spur or bevel attachment, is placed with a special cover which has a cast raised boss as shown in Figure 8. This raised boss is used to guide a 5" soil pipe to keep the soil pipe centered around the input shaft and provides the access necessary for operating the butterfly valve with a tee wrench. The entire gear case and valve assembly are of high strength design capable of withstanding the most adverse earth loads and ground water pressures. Many successful installations have proved the merit of completely burying butterfly valves used for distribution main service and similar applications.

In discussing gear units for submerged service, it is proper at the outset to eliminate valves which are installed in vaults subject to periodic rain flooding. Most of the standard gear units are suitable for conditions of this nature. If the flooding of the vault extends over any abnormal length of time, a good precautionary measure is to remove the gear case cover to check for water, and also to add new grease if necessary. For valves completely submerged, it is quite common to have the manual gear unit above water level. This is only practical for valves submerged at relatively low depths. For valves located at a considerable depth, the connecting of the gear operator to the valve shaft is very difficult. The first difficulty is the full required valve torque must be transmitted through the connection, since there is no gearing between operator and valve shaft. This leads to rather heavy bar (in most cases heavy tubing) not so much from the standpoint of stress in this member, but mainly due to strain in the form of angular deflection of the connecting member. Angular deflection can create serious problems because the butterfly disc can develop a "flutter" with the disc not connected to its gear operator by a rigid member, but by a member which acts like a spring or torsion bar. Angular deflection can also cause difficulty with proper seating if the "wind up" is excessive. Another problem in connecting gear operators located above waterline, to valves which are submerged, is that the valve shaft axis must be perfectly in line with the operator output axis. The reason for this is that any misalignment will create an eccentricity which will wear the valve and operator bearings and also create stresses in the connecting rod or tube. U-joints and similar connections are usually not practical due to the high torsional loads to be transmitted. The most economical and practical approach to operating a valve under considerable head is the use of a gear operator suitable for complete and virtually continuous submergence.

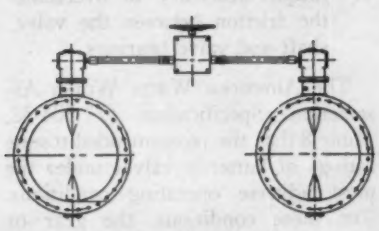


Fig. 7. A MITRE box drive.

The basic design of a gear or screw unit for submerged service is identical to the unit described above for buried service, except the boss for the 5" soil pipe can be eliminated. Units of this type design can usually withstand pressure forces up to a maximum of 65 feet. It is a practical approach on installations where a periodic (approximately yearly) de-watering, allows for inspection and grease packing as required. For higher heads or more critical installations, a "pressurized" gear unit is recommended. Pressure in the gear case is maintained by a column of oil of specific gravity approaching 1.0, with the reservoir for the oil being located above water level. A sight glass gives visual indication of whether oil is leaking out of the gear unit thru a damaged seal. Connecting the oil reservoir can be directly by an oil line to the gear case, or by means of a pipe connecting directly to the gear unit at the input shaft area. The extension of the input shaft passes through the center of this pipe, on up to the operating deck above. This pipe need not be overly large since the connecting shaft, driving the gear reducer, can now be fairly small in diameter due to the mechanical advantage of the gear reducer. A number of successful installations of this type

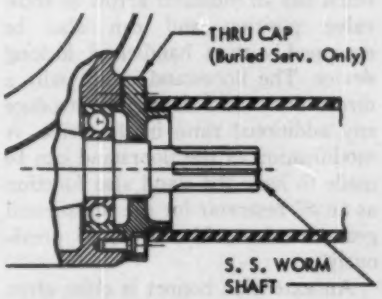


Fig. 8. A SPECIAL COVER which has a cast raised boss.

have been in operation for several years. The earliest and most noteworthy are the Stone Canyon and San Fernando reservoir installations of the Los Angeles Department of Water and Power where intake tower valving is operated with gear operators completely submerged and gear

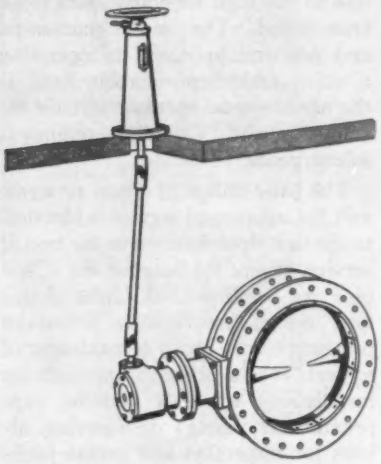


Fig. 9. A FLOORSTAND drive shaft.

cases pressurized. The use of submerged gear or screw operators is a sound design approach to operating a submerged butterfly valve, provided the economics of the various factors involved point to this solution.

Operator Extension Devices

Quite often the point of operation of the butterfly valve and the valve itself are some distance apart such as in submerged units. One of the most common devices used in these cases is the floorstand drive as shown in Figure 9. The floorstand drive shaft is connected to the worm gear reducer by means of an extension stem and two universal joints. The universal joints serve the function of compensating for any field misalignment of floorstand output shaft and gear reducer input shaft. The floorstand has an indicator arrow to show valve position and can also be equipped with a handwheel locking device. The floorstand is normally a direct drive and does not introduce any additional ratio in the drive. A modification of the floorstand can be made to have the stand also function as an oil reservoir for the pressurized gear case assembly described previously.

An extension bonnet is quite often useful in applications where it is desirable to have the gear or screw operator at some distance from the valve itself. The extension bonnet is shown in Figure 10 and can be used for buried valves to bring handwheel above grade, to bring operator up to operating deck elevation, or to prevent interference with other equipment by moving the operator further from the butterfly valve. The use of an extension bonnet above lengths of 18 to 20 feet is not recommended as a general practice since the reflection due to torsional loads in the connecting members creates the same difficulties of disc "flutter" and improper seating mentioned.

The direct torque drive shown in Figure 11 might be mentioned briefly. This assembly has the gear or screw operator mounted on a floorstand and full valve torque is transmitted directly to the valve shaft by a tube (commonly referred to as a "torque tube"). This method of operation is quite useful for installations where manual units are originally specified but future plant automation would require electric motor operation. Most gear and screw units are adaptable to motorizing after installation therefore the torque tube drive is required, since a submerged motorized unit is not practical.

Many other variations of operator extensions are available which include extended input shafts, mitre box arrangements, angle floorstands etc. For any special applications of this type it is best to consult an engineer of your valve manufacturer for a recommendation.

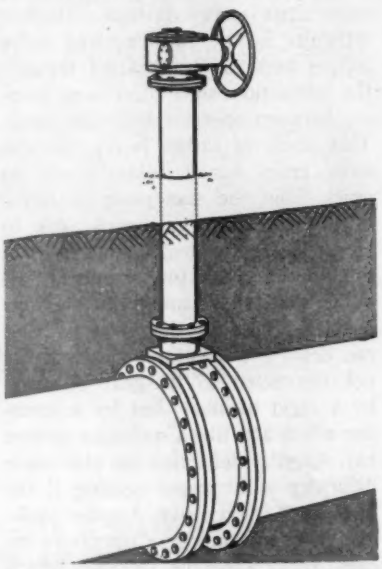


Fig. 10. THE EXTENSION bonnet.

Factors Governing Operator Selection

In all of the foregoing sections the matter of "output torque" was only touched briefly. This output torque represents the torsional output of a

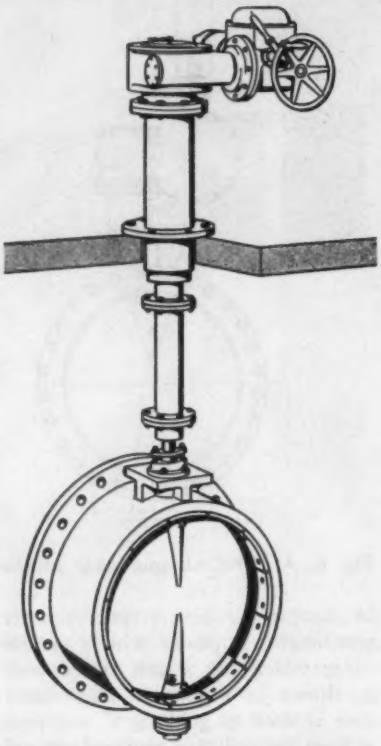


Fig. 11. THE DIRECT torque drive.

drive unit required to overcome the torsional resistance of a butterfly valve. This torsional resistance consists mainly of the following:

A. Seating torque—the torque required to create the necessary displacement of rubber to effect tight shutoff at rated pressure.
B. Fluidynamic torque—the torque needed to overcome the tendency of the butterfly valve to move closed when in a flowing stream—commonly referred to as to the aerodynamic or lift effect.
C. Bearing friction torque—the torque necessary to overcome the friction between the valve shaft and valve bearings.

The American Water Works Association Specification C 504-58, Table 8 lists the recommended torque ratings of butterfly valves under the most adverse operating conditions. For these conditions, the gear or screw unit for manual operation of

the butterfly valve, is simply chosen to equal or exceed these values. In the development of Table 8 of C 504-58 the operator ratings were chosen mainly for distribution main or "line break" service. For less severe design criteria, economy can be effected if the operators are sized to actual design conditions, while still maintaining the conservative safety factors of the AWWA Specification. This approach avoids costly "over-design" of installations.

Other factors beside torque considerations have an influence on the selection of manually operated gear or screw operators. One of the factors is that the gear or screw set, or special devices attached thereto, shall form a "self locking" or "not self-winding" unit. Another factor is that the manual effort to operate the butterfly valve should be kept to the minimum of what one man can reasonably exert. The days of "valve teams" or crews being sent out to operate some of the older valve types can thus be avoided. Closing speed of manual operators should also be considered, as well as the various installation configurations available.

Closure

The data in the foregoing article are by no means complete but were meant to point up some of the more important aspects of manual operators as related to butterfly valves. With the progress being made in the water works industry today, new applications of butterfly valve equipment are found and new problems require solving. If the cooperation between the water works engineer, valve engineer and operator engineer displayed over the past dozen years or so is any index, new and better equipment and installations will be the result in the future.

How sewage pumping is made easier with an Ampli-Speed magnetic drive

by Warren J. Birgel
Electrical Engineer
Electric Machinery Mfg. Company

W. J. Birgel

For years a common method of varying the speed of sewage pumps to match flow rate was by use of wound-rotor induction motors. In recent times, however, a new electrical device has won wide acceptance for its efficient speed control capabilities. This device is the eddy-current slip coupling, or magnetic drive.

With a magnetic drive installed between a constant-speed motor and the pump, pumping speed is adjusted with a simple potentiometer control.

The constant speed electric motor-magnetic drive combination provides an all-electric system that offers distinct advantages in planning new pumping installations or in redesigning older ones. Here's how:

Smaller Wet Well. With a magnetic drive on one or more pumps, the wet well or grit chamber can be made 25-35% smaller because it must handle only average flow, rather than maximum flow. With constant-speed drivers, the wet well must be designed for maximum flow.

Improved Plant Performance. With adjustable speed pumping, sewage feed through the plant is more even . . . the surging associated with constant-speed pumping is eliminated. In some cases, this makes it possible to avoid kilowatt demand penalties.

Less Pump Wear. With constant-speed pumps, the sudden-start surging of sand and gravel into the pump can often damage the impeller and casing rings. With a suitable automatic control system and magnetic drive, grit does not settle out because pumping is continuous. Abrasives move into the pump in suspension, with far less chance of pump damage.

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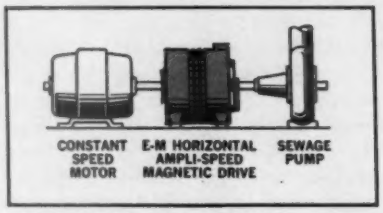

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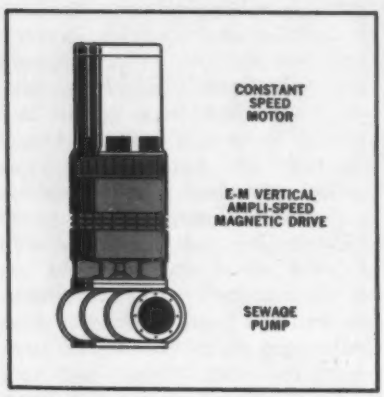

VERTICAL INSTALLATION requires no more floor space than constant-speed motor. Magnetic drive becomes integral with motor. E-M builds vertical Ampli-Speed Drives in a wide range of ratings.

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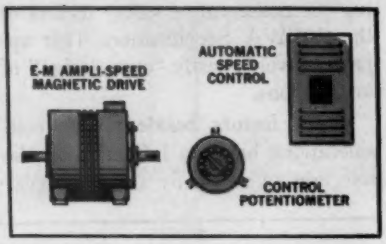

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Butterfly Valve Actuators

Part II—Use of Electric Motors

by A. L. MYERS
Allis-Chalmers
York Works
York, Pennsylvania

■ ELECTRIC MOTOR operated butterfly valves have found wide acceptance in water and sewage plants and in many industrial and other utility plants. They are used in all types of applications in the water and sewage field. Some of the standard water works applications are for the control of the usual filter influent, effluent wash and drain functions. An outstanding example of this type of application is the Torresdale Filter Plant in Philadelphia, Pennsylvania where the back wash cycle is initiated by pushing a button and the cycle proceeds to completion automatically. The cycle can be interrupted, and started again by merely pushing additional buttons. A small portion of the valves used in the plant are shown being assembled in Figure 1. Other applications are pump suction and discharge control on both high and low pressure systems and for bypassing various functions such as rapid sand filters, etc. Other uses include the regulation of pressure and flow in distribution systems and isolation of portions of systems. One of many unusual applications is the use of a time-clock controlled motor operated valve for furnishing off-peak water to a golf course in California.

There are many factors involved in applying electric motor operated butterfly valves. After the proper valve has been chosen the minimum information required for selecting the motor operator includes current characteristics, timing to fully stroke the valve, torque to actuate the valve, motor characteristics, and the requirements for any auxiliary equipment such as manual operation, extra limit switches, etc.

The basic electric motor operator consists of a reversible electric motor which operates through a speed reduction, which can be of the worm and gear type, spur gear or level gear type, or a traveling nut type, or any combination of these, to drive the valve shaft. Also, a set of switches which disconnect the current to the motor when the valve reaches the full open and full closed positions, or any intermediate position is required. To this basic unit many features can be added.

Sizing of Basic Unit

To select the proper size of the basic unit, the torque requirements of the valve and the desired operating time are required. The torque required to actuate the butterfly valve is a function of the flow, line pressure, and seating resistance. Minimum operator torque for most adverse conditions have been established by the American Water Works Association for rubber seated and metal seated butterfly valves as built to their standards and as described in AWWA bulletin C504-58 for rubber seated butterfly valves and bulletin C505-58 for metal seated butterfly valves. However, there are many applications where the most adverse conditions will never be encountered and the actual torque should be computed. By supplying the actual flow and shut-off conditions imposed on the butterfly valve to the manufacturer, the manufacturer can compute the actual required torque.

Features and Accessories

The motor usually furnished is one of three basic enclosures: a general enclosure, NEMA 1; weather-proof, NEMA 4; and explosion proof, NEMA 7. Other types can be furnished for very special applications if required. The motor can also be furnished with various insulations such as Class A, Class B and Class H as required. Motors are usually available for any voltage, phase, cycle and direct current. Most electric motor valve operators are designed for on-off service and consequently are normally equipped with intermittent duty motors rated for 5 or 15 minute service. When there are possibilities of prolonged operation, it is necessary to use either 30 minute duty motors, or continuous duty motors. For proportional control, a continuous duty motor is normally required. If precise positioning of the valve is required, the motor can also be equipped with magnetic brakes to eliminate any motor drift.

Limit switches, in addition to those required to limit valve travel, can be supplied for actuating position indicating lights, for interlocking valve action with related equipment, etc. When extra switches are required, the type, rating, and number of contacts should be specified. Another type of switch which is required on all but light duty operators is one that will stop the motor when excess torque conditions are encountered, such as obstructions in the valve, seized bearings, etc. This torque switch can be installed to function when the valve is closing, or opening, or two switches can be supplied to fully protect the valve and operator in both opening and closing cycles.

When there is an electric failure, the electric motor operated valve remains in the last position, except for those equipped with dual motors and standby power and the necessary interlocking relays. In many cases, it is desirable to have the operator equipped with an auxiliary handwheel for manual operation on power failure. The auxiliary handwheel can be furnished in various types. One type is where the handwheel is engaged by depressing a clutch lever with the handwheel being automatically disengaged when the motor is energized. The handwheel does not turn the motor rotor and the motor will not turn the handwheel. This type is called motor preference. In the manual preference type, the handwheel is pulled out to operate manually and must be pushed in to return to motor operation. There are various other types such as continuously connected handwheels which turn every

time the motor runs and a removable handwheel which fits over the nut. This latter type can be fitted with an interlock device so the motor operator cannot be operated unless a cover is placed over the nut.

A reversing mechanism, such as a controller or switch, must always be furnished to actuate the valve. For the small motor operator designed for single phase current, a simple single pole, double throw switch is normally sufficient. However, for larger motors and multiple phase applications, a reversing relay controller is necessary. In addition to the relay an actuating device is required. Where the application only requires the valve to be fully open or closed, a simple station with open, stop and closed push buttons is normally sufficient. Of course, refinements of the push button station such as indicating lights, are frequently desired. The normal practice is to have a red light and a green light with red indicating closed, green indicating open and both an intermediate position.

In addition to the manual push button station, many other devices can be used to control the motor operated valve in response to many variables such as pressure, flow, level, density, weight, thrust, temperature, position, etc. These devices can originate a simple on-off signal which merely opens or closes the valve. This type of operation is desirable when the motor operated butterfly valve is used on pump discharge service and the actuating device is a contact in the pump motor controller. They can also originate any proportional signal which will position the valve such as a pressure or flow regulating device. Positioning is usually accomplished by utilizing an electronic relay which incorporates a Wheatstone bridge. This application is illustrated by the simple diagram in Figure 2. The transmitter translates a signal, such as flow, level, etc. into a mechanical motion which actuates a slide wire or differential transformer which upsets the balance of the electronic relay. This causes a contact to close which energizes the reversing controller causing the valve to open or close as required. The movement of the valve also actuates a slide wire or differential transformer which feeds back to the electronic relay, and then the circuit in the relay is balanced a contact is open which, through the reversing controller, stops the valve action.

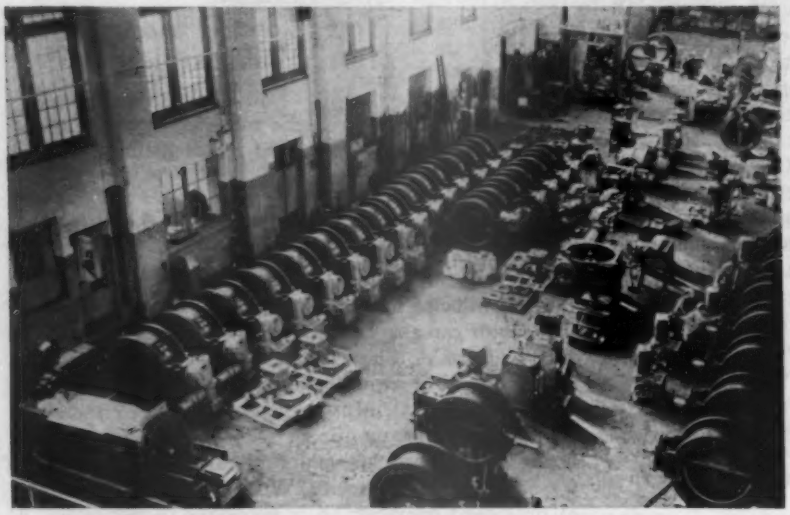


Fig. 1. RUBBER SEATED butterfly valves on assembly floor.

Many times it is desirable to know the valve position. As related before, one means is the use of indicating lights, but this only indicates whether the valve is in the fully opened, fully closed, or in an intermediate position. By equipping the motor operator with a slide wire the valve position can be indicated on a voltmeter calibrated in per cent or degrees open. For very accurate position indication, Selsyns can be used.

There are many refinements which can be obtained from the various manufacturers, and every year more refinements are being introduced. In the past several years, the reversing contactor has been removed from its separate wall mounted enclosure and has been incorporated within the motor operator enclosure. Push buttons and indicating lights have also made the same move to the operator enclosure. These integral controls are particularly advantageous where the valve is to be controlled locally, where space is at a premium, where the location is outdoors, etc. There also is the economy of lower installation and maintenance cost. Another innovation is the two-speed operator which uses a change of speed gear box actuated by magnetic clutches. This feature can be used for pump check service where it might be desirable to slowly close the valve to an almost closed position to avoid water hammer, then finish closing the valve rapidly to prevent backflow through the pump. As time goes on, more features will be added to make the electric motor operated butterfly valve one of the most versatile pieces of valve equipment on the market.

Operator Selection

To aid in the selection of the electric motor operator, the required basic information is tabulated as follows:

Available current characteristics—voltage, phase, cycle.
Valve torque requirements.
Time to fully open or close valve.
Type of enclosure and insulation.
Is auxiliary handwheel required? If so, what type?
Are additional limit switches required? If so, number required number of contacts per switch, rating and type, if special type required.
Type of operation—Open-close or positioning.

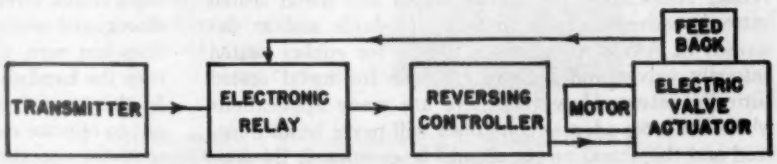


Fig. 2. BLOCK DIAGRAM for valve positioning control.

Accessory equipment such as reversing controllers, push button stations, slide wires, extra limit switches, etc.

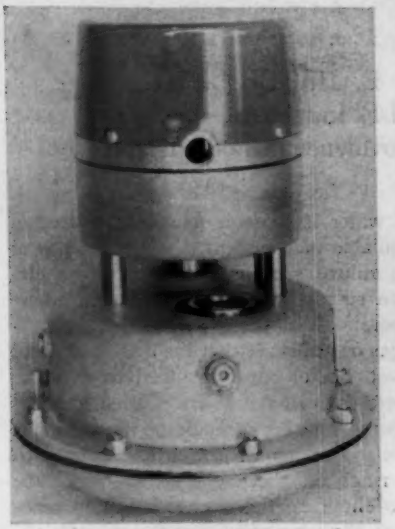


Fig. 3. SMALL VALVE actuator which can be mounted directly on the valve shaft.

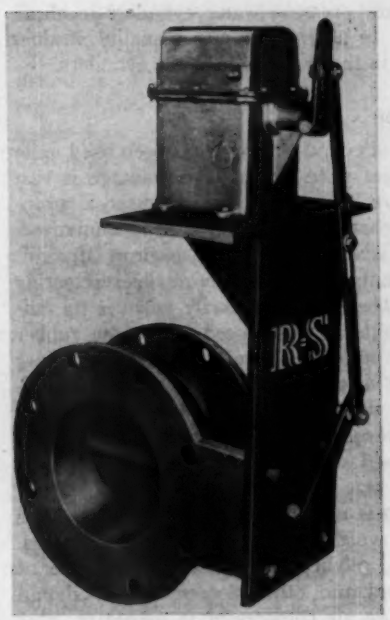


Fig. 4. A DAMPER motor which can be adapted for small valves.

To select the specific type, it is best to approach the various valve electric motor operator manufacturers as there are many types of electric motor operators available. For small valves, a small unit is available which can be mounted directly on the valve shaft and can be equipped with auxiliary limit switches, torque switches, continuously connected handwheel, etc. as shown in Figure 3. Also, for small valves, the various damper motors can be adapted with one example as shown in Figure 4. For larger valves, a larger, more rugged unit is required which is available from a number of operator manufacturers in almost every conceivable combination of features as described in this article. Some of these various operators are shown in Fig 5.

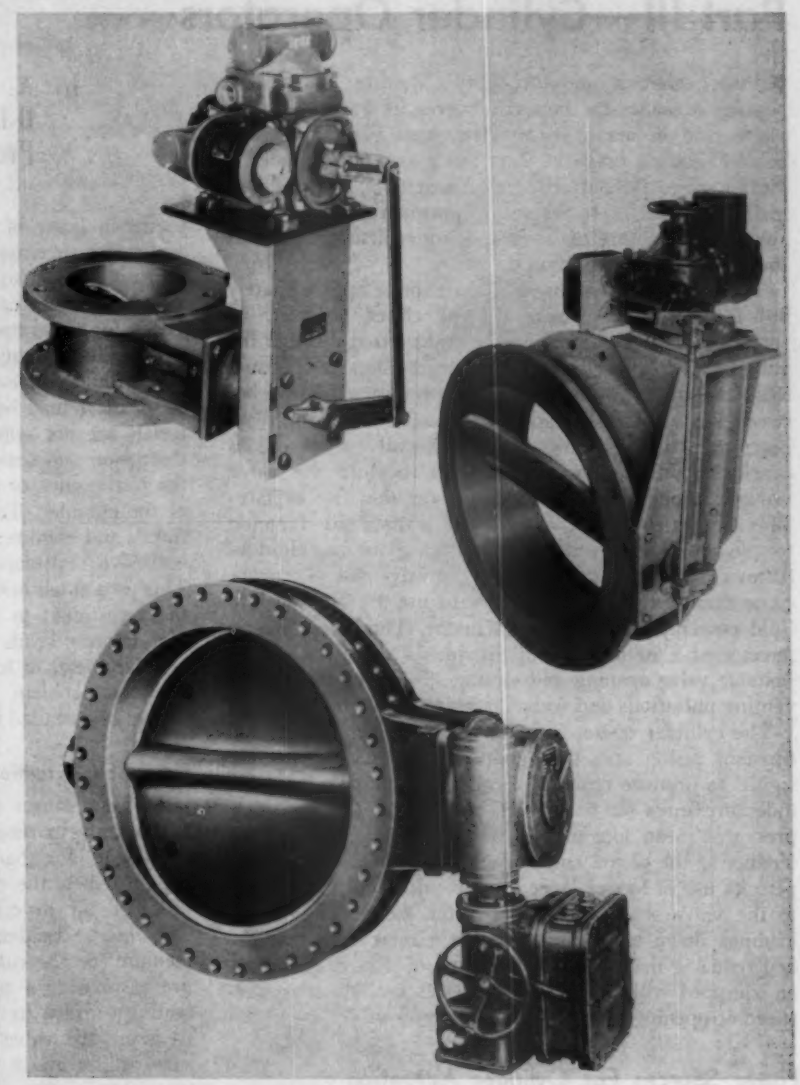


Fig. 5. VARIOUS OPERATORS for larger valves.

Wherever electricity is available, the electric motor operated butterfly valve provides efficient, reliable, automatic control of many operations.

Butterfly Valve Actuators

Part III—Cylinder Operators

by A. E. HATCH
B-I-F Industries, Inc.
Providence, Rhode Island

■ THE CYLINDER operator, at this writing, is the most popular actuator for butterfly valves in water filtration plants and in many sewage treatment plants. Reasons behind its wide usage in these fields are: the cylinder is ideally suited for butterfly valve actuation; there is normally a source of hydraulic or pneumatic power available for other services and it is convenient to use this source for valve actuation.

The butterfly valve disc and shaft rotate approximately 90° from the full open to the full closed position. To rotate the disc, a torque must be transmitted through the valve shaft to the disc to overcome resistances opposing this movement. These resistances are seating friction between the valve disc seating edge and the rubber seat; bearing friction resistance between the valve shaft and its bearings; and the forces that tend to close the valve brought about by water flowing over the disc surface. This last phenomenon is referred to as fluid dynamic torque and is due to the air foil effect of the line fluid as it flows past the leading edge of the valve disc. To overcome these forces, it is desirable to use a relatively low fluid power pressure in the actuator. This keeps maintenance at a minimum and provides a smooth and adjustable valve opening and closing speed, helpful in preventing pulsations and water hammer in the pipeline.

The cylinder operator, because of its long stroke and constant piston area throughout the stroke, can be designed to produce required torques at relatively low cylinder pressures (in the 50-100 psi range). Low cylinder pressures mean longer life and less leakage and maintenance at the piston rings or cups. The long stroke also permits use of longer lever arms connecting the cylinder to the valve shaft, thus keeping the stem and bearing loadings down to a minimum, again increasing the life and reducing maintenance. The ports of the cylinder may be equipped with flow control devices for adjusting the speed of opening or closing the butterfly valve.

Power Sources For Cylinder Actuation

Water Actuation

Water power has been used successfully for many years as a source of cylinder actuation, especially in water filtration plants where the supply is always available. Its advantages, other than convenience, are primarily that it is an incompressible fluid and provides instant response for positive positioning of the valve disc at a constant rate. The constant rate is most desirable in a rubber seated butterfly valve, as the life of the rubber seat is dependent upon the speed which the valve disc enters or leaves the rubber seating surface. Rapid movement of the disc across the seat tends to distort the rubber and increases wear. While it is not the intent of this article to cover valve controls but simply the actuator itself, it is basically true a cylinder with an incompressible fluid will assume a set position faster and with less overshoot than cylinders actuated by compressible fluids. One other factor in favor of water is there is usually a source of water pressure available independent of electrical power and not subject to failure, such as city water or an elevated tank that can supply water pressure in an emergency for valve operation.

The disadvantages of water are that the discharge from the cylinder on each stroke must be piped to a drain. Also, there may be a corrosion problem if adequate materials are not selected for the internals of the cylinder. Corrosion and scale in the cylinder can cause damage to the piston cups or rings and thereby affect the efficiency of the cylinder. To eliminate this many valve manufacturers and engineers have recommended the use of non-corrosive materials on the cylinder heads and pistons. This is a small initial added expense, but it is well worth the investment to insure long and trouble-free cylinder life. Bronze heads and pistons have become the most popular metal in low pressure water cylinders to eliminate this problem. In all installations a quality strainer should be installed in the supply line to the cylinders.

Pneumatic Actuation

Air, as a source of cylinder power, has been used quite successfully in recent years. Its main advantage is that it is clean, for there is no exhaust fluid disposal problem. Further, the corrosion problem can be minimized, provided air dryers and filters produce clean, dry air. The main disadvantage of a compressible actuating medium for the rubber seated butterfly valve is its failure to provide a constant disc speed across the rubber seating surface as outlined above. Unless utmost care is taken, the valve disc remains full closed until pressure builds up in the cylinder sufficient to overcome the valve seating torque. The disc then jumps off the valve seat at a speed which can be detrimental to the life of the rubber seat. On non-tight closing butterfly valves, this problem is not a factor and the use of air as a power source is widely used. Air actuated cylinders, in many instances, require the additional expense of providing air dryers and other accessories. It should also be noted that an air compressor is necessary, plus adequate storage compression tanks to provide pressure in the event of power failure.

Oil Actuation

Oil pressure has not been used to any great extent in the past in water filtration and sewage plants as the advantages have not outweighed the additional expense of providing a complete oil system purely for valve actuation. Occasionally, in large plants where there is a freezing problem eliminating the use of water, and the use of

a compressible fluid such as air is not desirable, the hydraulic oil system is the answer and has been used very successfully. Another advantage of an oil system is that the corrosion problem in the cylinder itself is held to a minimum. The cylinder pressure is dependent, as is the pneumatic system, on air compressors and pump motors and is, therefore, susceptible to power failure.

There are combinations of this power actuation which, while more expensive, are used occasionally, such as air cylinder operators with tandem

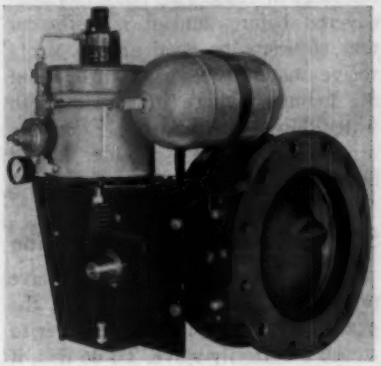


Fig. 1. RACK and gear arrangement.

hydraulic cylinders to provide smooth operation and eliminate the jumping action of the valve unseating. In most systems of this type, the hydraulic cylinder has a connection between the cylinder ports with an adjustable orifice in it. This allows the oil to recirculate while the speed of valve opening or closing can be governed by the adjustable orifice.

Mounting Arrangement of Cylinders on Butterfly Valves

Rack and Gear

The rack and gear arrangement in Fig. 1 has been promoted by some manufacturers, and it has the advantage of producing a constant torque on the valve shaft throughout the entire stroke of the cylinder. It also has a rigid mounted cylinder with a guided piston rod to eliminate any side thrust on the piston rings or piston rod bearings. This type of linkage is most generally used on open and shut applications and not for throttling as any back-lash or slippage in the gearing would cause a fluctuating control system. In addition to the possibility of "play" in the gearing, this linkage is also susceptible to foreign matter jamming between the gearing and the piston rod rack. Considerable thrust is required to hold the piston rod rack onto the gear, and the forces imposed must be overcome by the cylinder piston.

Swivel

The swivel type construction as shown in Figure 2 is the most widely adopted and has the advantage of being very compact with practically no side thrust on the piston rings and piston rod bearings. The cylinder lever arm can be arranged on the valve shaft to produce the maximum torque where it is needed most, and a minimum torque with the valve open where bearing friction is practically the only torque to be overcome. This allows for a more economical installation that provides ample operator power to the valve shaft. The only disadvantage to this linkage is the cylinder pivots and flexible hose must be supplied between the cylinder ports and a rigid connection on the valve bracket. Hoses are now available that will provide many years of trouble-free service.

Toggle Link

The toggle link, as shown in Figure 3, has a rigidly mounted cylinder, and has been used successfully for many years. It is not as compact or as efficient an arrangement as the

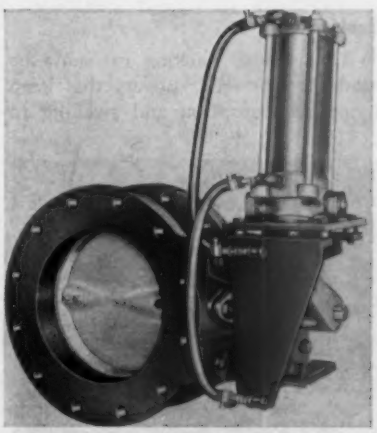


Fig. 2. SWIVEL TYPE cylinder arrangement.

other two types, and there is more side thrust on the piston rod.

Factors Affecting Cylinder Operation and Life

AWWA Specifications

While it is not the intent here to have detailed discussion of cylinder design, a few items will be discussed that could aid the user in selecting cylinders that will give him the long service he requires. American Water Works Association Specification C-504-55-58 outlines materials of construction for pneumatic or hydraulic cylinders. The specifications are based on long field experience and cylinders purchased to these specifications will give excellent service.

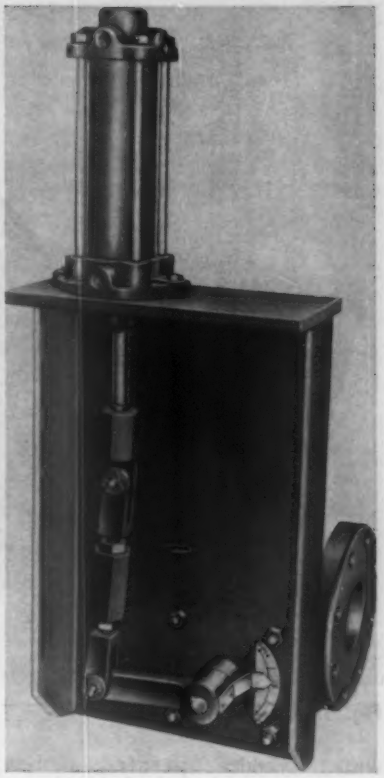


Fig. 3. TOGGLE LINK cylinder arrangement.

Cylinder Pressure

There are a few basic features affecting cylinder life and maintenance that we will cover here, these being pressure, cylinder roundness and wall finish, piston cups or rings, piston rod finishes, and dirt or scale. Regarding pressure, it is fairly safe to say maintenance goes up with the cylinder pressure. As the pressure goes up, there is more elongation of the tie rods or working of the seals between the cylinder head and piston barrel, and simply more all-around strain on cylinder working parts. As a rule of thumb, we would recommend that cylinder pressure be kept under 150 psi, with pressures in the vicinity of 50-100 psi being about the ideal for

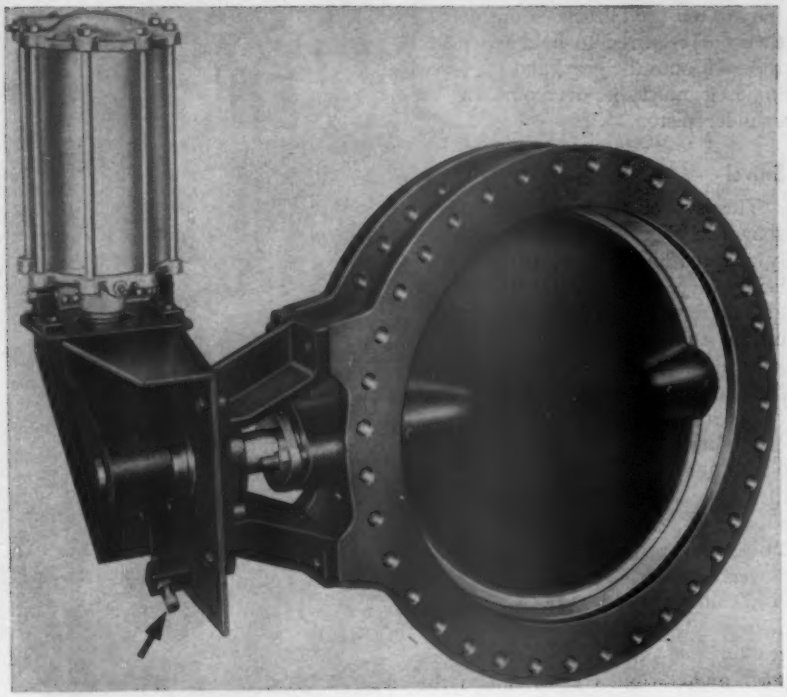


Fig. 4. ADJUSTABLE stops.

water cylinder operated, rubber seated butterfly valves.

Roundness

Roundness is the heart of all cylinder operation; the cylinder barrel, piston, and piston rings, or cups must all fit together with fairly close tolerances and be absolutely symmetrical around the piston rod. To assure this until a few years ago, water works engineers and users called for cylinder barrels of cast iron lined with bronze tubing. As it is not desirable to hang a heavy cast iron cylinder on the butterfly valve, manufacturers in later years have switched to stronger, more rigid cylinder barrels of centrifugally cast bronze with excellent results. The wall finish on the inside of the cylinders is also very important. AWWA specifications call for the inside diameter to be honed to at least a 15 RMS (Root Mean Square) finish.

Piston Seals

Three basic types of piston seals have been used, the first being cups of leather construction. While these have been used for many years. their disadvantages are that they have a high friction coefficient against the wall of the cylinders, and they absorb water, causing swelling. O-rings have been used in many instances and, while their friction is low, they do have a tendency to twist or spiral in the piston slots. In recent years, "U" or "V" packings have been used with much success. This type of packing can be supplied with a square back to eliminate the tendency to twist. Friction is low with this type ring.

Packing

All types of packing can now be made of synthetic rubbers that keep moisture absorption and swelling to a minimum. It is particularly important that the piston rod have a hard finish and be of a non-corrodible material. AWWA specifications call for stainless steel piston rods having a 5 to 10 RMS finish with a surface of hard chrome plate, a minimum of .0005" thick. This prevents leakage on the piston rod itself. The cylinder should also be equipped with a dirt wiper to clean the piston rod before it enters the cylinder.

The most common cause of cylinder trouble is the presence of dirt or scale in the water, damaging the piston rings or cups. This point has been covered before, and it is sufficient that strainers be used and non-corrosive material be used throughout the cylinder where in contact with water. However, the trouble that can arise from scale in a cylinder cannot be stressed too strongly.

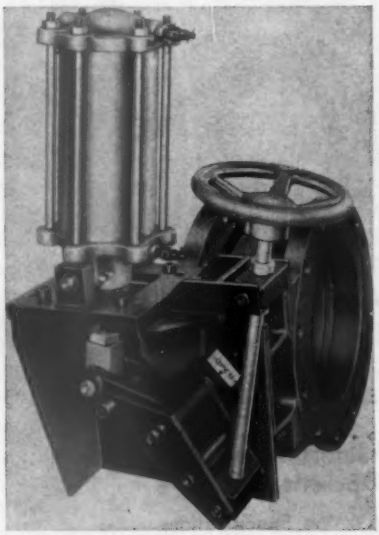


Fig. 5. AUXILIARY manual.

Standard Methods of Actuation

A double-acting cylinder must have pressure applied to one side of the piston and removed from the other to stroke a butterfly valve. To do this, it required either one 4-way valve, two 3-way valves, or four 2-way valves in the control system to the cylinder. In most instances, a single 4-way valve is used. These valves may be hand actuated by lever, remotely actuated by solenoids, or driven by diaphragms, either pneumatic or hydraulic. Four-way valves are available with neutral positions so that a valve may be stopped in an intermediate position for throttling or control purposes. For prolonged throttling, a positioner should be used. A positioner is an instrument that positions a valve to correspond to a signal received from a manual loading station or other device such as a level or flow controller. Should the valve tend to drift from the position called for by the controller, the positioner takes corrective action and maintains the proper position.

Accessories Available

Adjustable Stops

All cylinders or their mounting parts should be provided with adjustable stops to terminate the rotation of the valve disc. These stops may be mounted where they are accesible as shown in Figure 4. A less expensive arrangement is to use the cylinder heads themselves as the

stops, making adjustments in the link between the cylinder piston rod and the valve lever arm.

Operating Speed

Where it is required to adjust the speed of the closure or opening, speed control valves are available for this purpose. Where accurate metering of the flow from the cylinder is required, flow control valves that furnish free flow in one direction and calibrated throttle flow in the opposite are available. Where it is not too critical an adjustment, simple needle valves may be utilized.

Auxiliary Manual Operation

Auxiliary Manual Operation is available with most cylinder operators as shown on Figure 5.

Valve Position Indicators

For position indication, all cylinders are equipped with local indication and transmitters are available for remote position indication, either pneumatically or electrically.

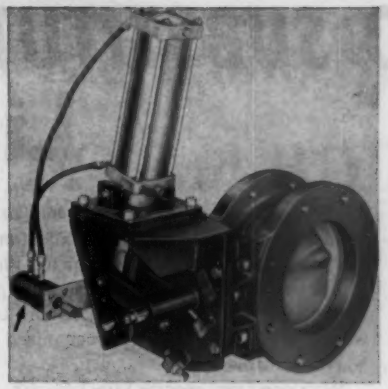


Fig. 6. 4-WAY VALVE positioner.

Valve Positioners

When cylinders are used on a control system, 4-way positioners are available, either all pneumatic or of the hydro-pneumatic type, as shown in Figure 6.

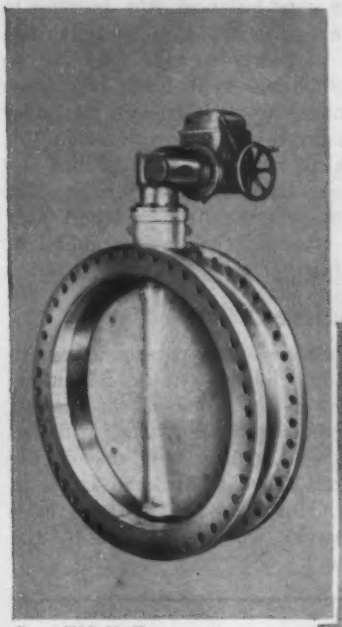
Fail Safe Protection

In some instances, it is desirable to have a valve closed immediately upon loss of power supply. This can be accomplished by the use of volume chambers to store enough air under pressure to close the valve once; or, it also may be accomplished by springs built into the cylinder. The springs are usually used where very fast speed of closure is required in the event of power failure.

Conclusion

We have briefly covered a few details on cylinder operators for butterfly valves and some of the reasons why they have gained such wide acceptance. Actually, any one of the sections above could be an article in itself. However, we hope this brief discussion will be helpful to the reader.

THERE IS NO SUBSTITUTE FOR LimiTorque



Type SMA LimiTorque operating a Henry Pratt Company 48" Butterfly Valve.

Yes! there is no substitute for LimiTorque. More engineers are recognizing this daily. A recent specification, from which we quote, "The motor operated valve shall be of the Philadelphia 'LimiTorque' type or full equal. Because this type has been proven in service similar to that for which this valve will be used and because of unsatisfactory results with other operators" . . . recognized the superiority of LimiTorque Valve Controls.

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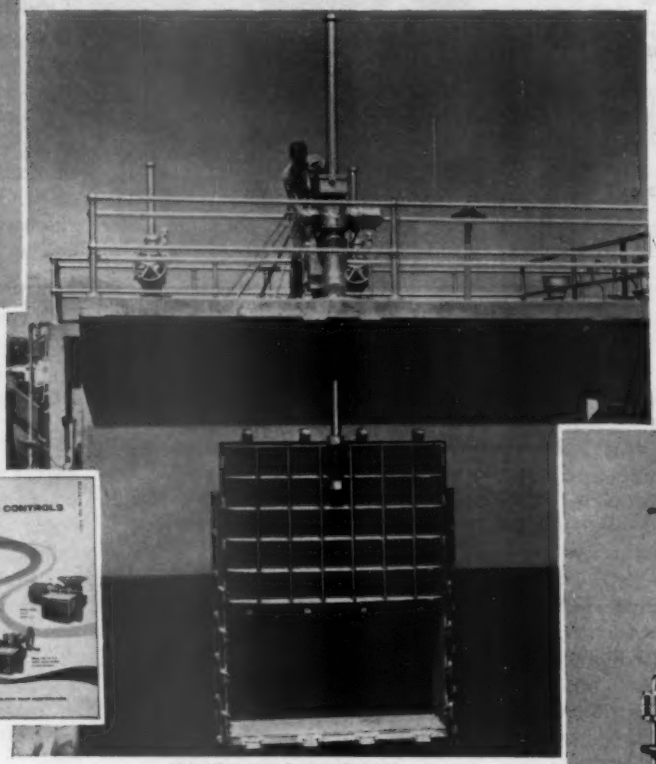

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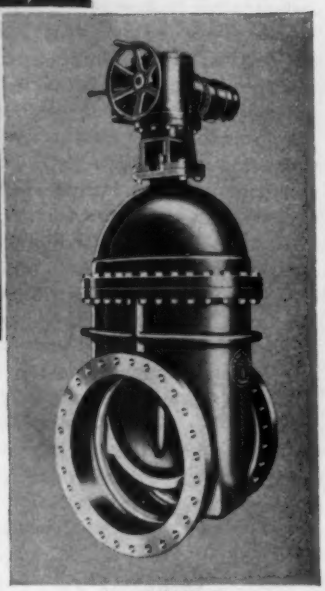

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New Platinum Electrode System Measures DO and BOD

by J. D. EYE, L. H. REUTER and K. KESHAVAN, respectively Assoc. Prof. Sanitary Engr, University of Cincinnati; Lieut., U.S. Army; Graduate Student, Sanitary Engr., University of Cincinnati

■ DISSOLVED OXYGEN (DO) and Biochemical Oxygen Demand (BOD) measurements have assumed a position of utmost importance in waste treatment and water pollution control. The dissolved oxygen test gives a measure of the ability of a water to support organisms which utilize free oxygen. The BOD determination is a measure of the amount of oxygen that will be used by bacteria as they decompose the organic components of wastes. The BOD test has become one of the most significant parameters for characterizing the pollutional aspects of organic wastes.

The standard test for dissolved oxygen (Winkler Test), as outlined in Standard Methods[12], consists of adding appropriate chemical reagents to a sample of water and measuring the chemical equivalent of dissolved oxygen present. The BOD test consists of measuring the initial dissolved oxygen level of an appropriately diluted sample and the oxygen level at the end of a stated period of time, usually five days. Only one dissolved oxygen test can be made on an individual sample. A BOD measurement requires several dissolved oxygen determinations; therefore, a large number of samples is required if many points are needed on a BOD versus time curve (Figure 1).

The standard tests for dissolved oxygen and BOD have many shortcomings and disadvantages which have not been overcome fully from a practical standpoint. Hence, investigators have devoted much time and effort to the development of more appropriate means for measuring these important quality characteristics. One of the most fruitful approaches has been the application of the polarographic principle to the analysis for dissolved oxygen.

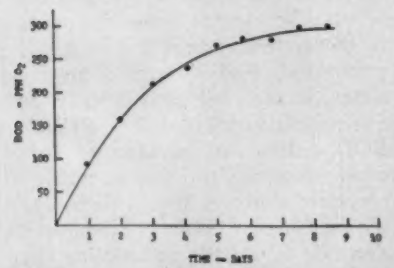

Fig. 1. TYPICAL BOD versus time curve for domestic sewage.

Polarographic Systems

General

A typical polarographic system consists of an electrolysis cell, a small highly polarizible electrode, a large non-polarizible electrode, a source of applied potential and a means for measuring current. It has been shown that as the voltage applied to a polarographic cell is increased, the amount of current flowing in the system at a particular EMF range will increase rapidly for a small change in applied potential whereas at other EMF ranges only slight variations in current will be noted for large increases in applied voltage (Figure 2).

Professor Jaroglav Heyrovsky, of Charles University, in 1922 investigated these peculiar current fluctuations and developed instruments for automatically recording the current versus applied potential. He concluded that the voltage necessary for electrolysis indicated the nature of the reacting substances, and that the current flowing is proportional to the concentration of the reacting substance.

Measuring Dissolved Oxygen by Polarographic Techniques

Investigators have found that dissolved oxygen in an electrolytic solution is easily reduced and produces a two-wave polarogram. Kolthoff and Lingane[7] explained that the first wave (Figure 2) is caused by the reduction of oxygen to hydrogen peroxide as indicated in the following equation:

$$O_2 + 2H^+ + 2e^- = H_2O_2 \text{ (Acid Solution)}$$

or

$$O_2 + 2H_2O + 2e^- = H_2O_2 + OH^- \text{ (Alkaline Solution)}$$

The second wave is due to the reduction of hydrogen peroxide to water or hydroxyl ion:

$$H_2O_2 + 2H^+ + 2e^- = 2H_2O \text{ (Acid Solution)}$$

or

$$H_2O_2 + 2e^- = 2OH^- \text{ (Alkaline Solution)}$$

In operation, the applied potential must be sufficiently low to prevent the discharge of hydrogen at the electrode surface. While oxygen can be reduced at two distinct potential ranges, operation in the lower range will give the most satisfactory results.

The actual current that can be obtained from a polarographic system is determined by the rate of supply of the substance being reduced at the cathode from the body of solution. The rate at which oxygen molecules diffuse to the cathode is dependent upon the concentration gradient between the electrode surface and the body of solution. From a practical standpoint, therefore, in dissolved

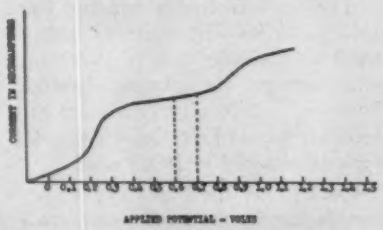

Fig. 2. TYPICAL POLAROGRAPHIC curve for oxygen.

oxygen and BOD analysis, the current flowing in the electrode system at constant temperature and viscosity is a function of the concentration of dissolved oxygen in a sample being analyzed.

Many investigators have attempted to develop a working polarographic system for continuous dissolved oxygen measurements. Spoor[8] developed a procedure for utilizing a dropping mercury electrode system for the continuous measurements of dissolved oxygen in flowing water. The water had to be maintained at a very low velocity, however, to prevent interference with the mercury droplets.

Rotating and stationary solid-electrode systems have been used for dissolved oxygen measurements and in many cases these have been superior to the dropping mercury arrangement.

Kolthoff and Lingane[7] showed that a rotating platinum microelectrode is perferable to a dropping mercury electrode for measurements of low oxygen concentrations because the diffusion current is much larger with a rotating electrode.

Allen and Powell[1] found no shift in potential for a rotating platinum electrode during reasonable lengths of operation. They obtained a linear relationship between the oxygen concentration and diffusion current although very close temperature control was required.

Giguere and Lauzier[5] investigated all types of electrode systems. They found that the rotating and stationary types were extremely temperature-dependent as well as sensitive to the type of electrolyte used in the cell.

Warshowsky and Schantz[13] used a rotating platinum electrode to determine the DO of aerated and agitated bacteria culture media containing actively respiring organisms. They also made DO measurements on salt solutions, getting results which agreed with the values as determined by the Winkler procedure.

The advocates of a rotating electrode cite its instantaneous adjustment to a steady state of current as an advantage. The spinning electrode, however, is difficult to maintain at a constant speed of rotation for the long periods required in BOD work.

Clark *et al*[3] used an oxygen- permeable membrane cover on a stationary platinum electrode to measure oxygen tension in blood. The membrane, although permeable to oxygen, was much less permeable to other dissolved materials. Clark, however, used the membrane to separate the measuring and reference electrodes, thereby causing high impedance characteristics for the system. Clark[4] later improved the system by combining the platinum-reference electrodes behind the membrane.

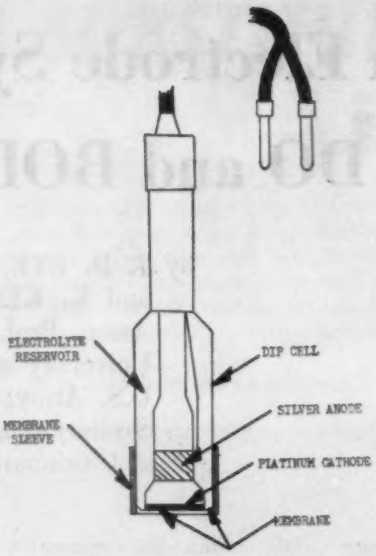

Fig. 3. ELECTRODE CELL.

Ingols[6], using a stationary platinum electrode, a calomel half-cell electrode and an alternating charge, determined the DO of samples of natural water and sea water. The electrode, however, would not work well with sewage. Certain enzymes in the sewage were suspected as being responsible for the difficulties.

Lynn and Okum[8], using a rotating platinum wire electrode, found that the speed of rotation beyond 500 ppm did not affect the measured current. Working with DO values ranging from zero to 36 ppm, they did not obtain a linear calibration curve of current versus DO concentration.

Watanabe and Leonard[14] reported on the use of a modified Clark electrode consisting of a plastic covered, stationary, combination platinum-reference electrode system. Current was found to be directly proportional to the area of the platinum electrode and inversely proportional to membrane thickness. The electrode was extremely temperature-dependent.

Ough and Amerine[9] found that the Clark electrode was suitable to measure the oxygen concentration in wines.

Carritt and Kanwisher[2] attempted to construct a temperature compensated plastic covered electrode. While their work was not completely successful, the errors resulting from changes in temperature were greatly reduced.

Sawyer[10] studied the Clark electrode and its application to oxygen and other gaseous measurements.

Biochemical Oxygen Demand Measurements by Polarography

General Description of Electrode System

The electrode system* used in the present study consists of a platinum cathode covered with a polyethylene membrane of two to four mils in thickness. The platinum cathode and silver anode are connected by a supporting electrolyte of potassium chloride. The electrodes are conveniently housed in a glass dip cell (Figure 3).

In operation, the polarographic cell is immersed in a sample to be analyzed for dissolved oxygen. A potential of 0.6 to 0.7 volt is supplied by a standard dry cell (Size D Flashlight Battery). At this operating voltage, dissolved oxygen is the chief substance that will be reduced at the cathode surface. Other materials can be reduced at this voltage, but, in general, they will not pass through the plastic membrane covering the cathode. As indicated earlier, the current flowing in the system is a function of the number of oxygen molecules being reduced at the cathode surface. This number in turn is directly related to the concentration of oxygen molecules within the body of the liquid; hence, the current is a measure of the concentration of oxygen in solution.

If oxygen measurements are to be made continuously, it is necessary the sample be stirred constantly so plating of the electrode surface does not occur. The current actually flowing in the system is amplified by a pH meter and read directly from the meter or recorded automatically on a potentiometric recorder. Reliable BOD results can be obtained only when reaeration of the samples is prevented during a test. This can be accomplished by placing a sample and electrode in a flask and sealing the

*Electrode system produced by Beckman Instruments, Inc., Fullerton, Calif.

flask properly. The sample being analyzed can be agitated with a magnetic stirrer.

Components of Electrode System

1. Plastic Cover for Electrode: The plastic membrane covering the cathode surface is an extremely important component of the polarographic cell. While the membrane must be permeable to dissolved oxygen, it should not be permeable to other ions which can be reduced at the operating voltage specified. The membrane also serves the important function of keeping the internal electrolyte in contact with the anode and cathode. Several materials have been utilized as a cov-

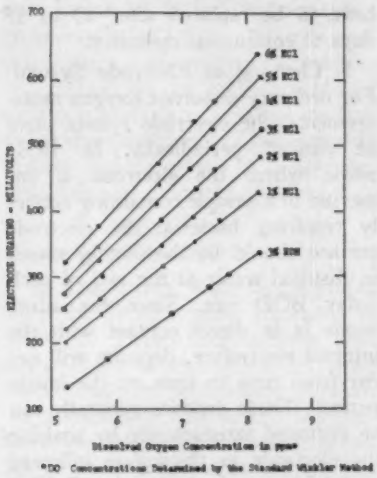

Fig. 4. EFFECTS OF INTERNAL electrolytes or dissolved oxygen measurements.

ering for the electrode surface, but, in general, polyethylene film appears to give better results and fewer difficulties than any other type of plastic film investigated.

The greatest difficulty noted in using polyethylene film is the fact that the thickness varies considerably for a standard gauge material. From the standpoint of sensitivity, a polyethylene film two mils thick is ideal, but because of the variation in thickness of a two mil film, reproducible results cannot be obtained. A film four mils thick likewise is variable in thickness, but the effect is much less noticeable than with a two mil film. The sensitivity and precision of a four mil membrane are not so good as for a two mil film, but the overall results for oxygen measurements are as good as those obtained by the standard chemical test. Polyethylene film three mils thick falls somewhere between the two and four mil thicknesses in operating characteristics and is probably the most satisfactory type to use for most oxygen measurements.

An attempt was made to use Teflon film because this material is more uniform in thickness than polyethylene. The sensitivity and precision of a Teflon covered electrode was far superior to a polyethylene covered system. Unfortunately, a long period of time was required for a Teflon covered electrode to reach stability, and the results seemed to change somewhat from day to day.

2. Internal Electrolyte: Several possible internal electrolytes can be used as a junction between the cathode and the anode. In this particular study, dilute solutions of potassium chloride and potassium hydroxide were investigated. In operation, it is important the reference electrode maintain a potential independent of the current flowing through the cell. Some investigators have recommended the use of potassium hydroxide rather than potassium chloride for the electrode system. The writers found that both electrolytes are satisfactory. A straight-line relationship was obtained between current flow and dissolved oxygen level although the actual values of current observed were dependent upon the strength of the supporting electrolyte (Figure 4).

Operation of Electrode System

1. Calibration; Before an electrode system can be used for routine dissolved oxygen measurements, a calibration curve must be established.

One of the basic difficulties in preparing a calibration curve for an electrode is the fact that no primary dissolved oxygen standards are available. It becomes necessary, therefore, to prepare a series of secondary standards by aerating samples of water for varying periods of time and determining the actual oxygen content of these samples by a standard chemical test. The calibration of the electrode, therefore, is entirely dependent upon the results obtained from a standard chemical test for dissolved oxygen.

At the operating voltage indicated, and at constant temperature, a linear relationship was observed between the current, or pH meter output, in millivolts, and the oxygen concentration (Figure 5). In practice, the precision and accuracy of the electrode procedure for measuring dissolved oxygen cannot be determined completely because of the fact that the results of this procedure must be

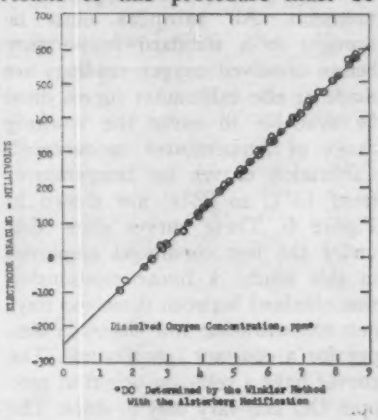

Fig. 5. CALIBRATION CURVE for electrode system.

judged on the basis of results obtained by a chemical test. It is possible, however, to measure the reproducibility of the electrode procedure, and in this study the reproducibility was found to be equal to that of the standard chemical test (Table 1).

Table 1

Reproducibility Data by the Winkler and Electrode Procedures

Dissolved Oxygen Concentration in ppm*	By Winkler Method	By Electrode
Series A		
Sample No.		
1	4.7	4.9
2	4.9	4.9
3	4.8	4.8
4	4.9	4.8
5	4.8	4.8
Series B		
Sample No.		
1	7.6	7.5
2	7.7	7.6
3	7.5	7.6
4	7.6	7.5
5	7.5	7.5
Series C		
Sample No.		
1	8.0	7.9
2	8.1	8.0
3	8.0	8.1
4	7.9	7.9
5	7.9	7.9
Series D		
Sample No.		
1	5.9	5.7
2	5.7	5.8
3	5.7	5.7
4	5.8	5.8
5	5.7	5.7

*Ten dissolved oxygen bottles were filled by siphoning water from the same sealed container for each series of data. Five of the samples were selected at random to be analyzed by the Winkler Method and the other five were analyzed by use of the electrode cell.

2. Temperature compensation: The temperature dependency of the electrode system imposes severe limitations on the application of this method to routine dissolved oxygen measurements. All samples must be brought to a standard temperature before dissolved oxygen readings are made or else calibration curves must be available to cover the working range of temperatures encountered. Calibration curves for temperatures from 13°C to 28°C are shown in Figure 6. These curves show that under the test conditions employed in this study, a linear relationship was obtained between dissolved oxygen concentration and electrode output for a constant temperature. The curves have a common origin at zero ppm DO and vary only in slope. The increase in slope per degree C increase in temperature is approximately constant for the range of 13°C to 28°C.

In routine BOD analysis, all samples are maintained at a constant temperature throughout the period of a test. Temperature compensation, therefore, is not necessary since the electrode system operates continuously under constant temperature conditions.

3. Initial Stabilization of Electrode System: When a cell is first immersed in a sample to be tested, a short period of time must elapse before a stable reading can be obtained. With a polyethylene membrane covering, a stable reading is achieved in one to three minutes. The period of stabilization is influenced by the rate at which oxygen molecules are brought from the body of the solution to the electrode surface. Since the current is proportional to oxygen concentration only under steady state conditions, stirring the sample hastens the process of equilibrium and greatly shortens the stabilization period.

4. Zero-Drift: In using an instrumental procedure for the continuous measurement of oxygen levels, for a period of five days, it is important that the system exhibit a low zero-drift. If the zero-drift occurs, it must be taken into account and its effect on the overall readings eliminated.

A detailed study was made of the zero-drifts of the dissolved oxygen electrode system. For periods up to seven days, the system was extremely stable and would not present a problem from this standpoint (Table 2).

Table 2
Zero-drift Study Using Varying Concentrations of Internal Electrolyte and Samples with Different DO Concentrations

Time	Dissolved Oxygen in Parts per Million	
	By Electrode*	By Winkler Method
Internal electrolyte—3 per cent solution of potassium chloride		
Initial Reading	8.1	8.1
1 day	8.1	8.2
2 days	8.1	8.1
3 days	8.1	8.1
4 days	8.1	8.2
5 days	8.1	8.1
6 days	8.1	8.2
7 days	8.1	8.1
Internal electrolyte — 1 per cent solution of potassium chloride		
Initial Reading	7.7	7.7
1 day	7.7	7.7
2 days	7.7	7.8
3 days	7.7	7.8
4 days	7.7	7.7
5 days	7.7	7.9
6 days	7.7	7.7
7 days	7.7	7.7
Internal electrolyte — 5 per cent solution of potassium chloride		
Initial Reading	7.9	8.0
1 day	7.9	7.9
2 days	7.9	7.9
3 days	7.9	7.9
4 days	7.9	8.0
5 days	7.9	8.1
6 days	7.9	7.9
7 days	7.9	7.9

*All tests conducted at 20°C. and similar operating conditions. All tests were on distilled water samples.

The small differences noted in Table 2 between the DO levels as measured by the electrode system and the Winkler procedure are within the limits of reproducibility of the standard Winkler test.

A zero-drift may occur if the same membrane and internal electrolyte are used for long periods of time. Apparently, the membrane tends to undergo some deterioration if exposed to mechanical and bacterial action for prolonged periods of time and the composition of the internal electrolyte also will change with respect to time.

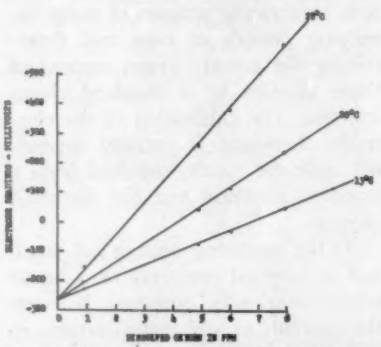

Fig. 6. EFFECT OF TEMPERATURE on electrode reading.

Battery deterioration, during extended periods of continuous operation of the electrode system, is the major cause for zero-drift. It is possible to prevent zero-drift from battery aging by replacing the battery at frequent intervals or by re-standardizing the electrode system before dissolved oxygen measurements are made. In most cases, the battery will have to be replaced after 10 to 15 days of continuous operation.

5. Cleaning of Electrode System: For ordinary dissolved oxygen measurements, the electrode system must be cleaned periodically. In BOD work, where the electrode is immersed in a sample containing actively respiring bacteria, the electrode surface should be thoroughly rinsed in distilled water at the end of each 5-day BOD run. Since the silver anode is in direct contact with the internal electrolyte, deposits will occur from time to time on the anode surface. These deposits generally can be removed satisfactorily by soaking the electrode in thiosulfate followed by soaking and rinsing in distilled water.

In this study, thiosulfate cleaning was used after three or four months of continuous operation.

Experimental BOD Measurements

A special adapter assembly (OM-2 Kit, No. 18900,* using a flashlight battery (Size D) as the source of applied potential, was coupled to an electrode cell and a Zeromatic pH Meter. Voltage readings were read on the millivolt scale of the pH meter. The BOD samples being analyzed were prepared in accordance with procedures outlined in Standard Methods[9]. A sealed, 1000 ml Erlenmeyer flask, maintained at a constant temperature, housed the sample and electrode cell. A thermometer was used to measure the temperatures of the sample at the time each voltage reading was recorded. A magnetic stirring device provided a homogeneous system and a continuous

*Beckman Instruments, Inc., Fullerton, Calif.

flow of oxygen molecules past the platinum electrode surface.

Nineteen 5-day, 20°C BOD tests were run using "grab" samples of sewage from the Little Miami Sewage Treatment Plant and the Mill Creek Interceptor Sewer of Cincinnati. One, two, and three per cent dilutions of sewage were used. The 5-day, 20°C BOD's of the sewage ranged from 180 to 325 ppm.

In these tests, two sets of dissolved oxygen data were obtained. One set of samples was analyzed by the standard chemical test while corresponding samples were analyzed with a stationary platinum electrode system.

The Winkler procedure was constant for all BOD tests, but the operating conditoins for the electrode system were varied to provide specific information on the reliability of the electrode procedure, the need for frequent standardization of the electrode system, and the effects of battery deterioration on electrode response.

Discussion of Results

Representative data accumulated from the BOD studies are listed in Table 3. These data indicate that with proper laboratory control, good correlation can be achieved between the standard BOD test and the electrode procedure. Of the nineteen series of BOD tests performed for this study, the maximum 5-day deviation between the dissolved oxygen concentration of a sample analyzed by the electrode method and a corresponding sample analyzed by the standard chemical test was 0.7 ppm. A majority of the 5-day deviations were between 0.2 and 0.5 ppm.

In almost all cases, higher BOD values were obtained with the electrode procedure than with the standard Winkler procedure. Two possible explanations for these higher values are: mechanical stirring of a sample maintains better contact between the organic matter and the bacteria and thus may give a higher BOD removal than can be achieved in the static system used for routine BOD analysis; the second possibility is that the organisms can oxidize certain plastic components of the electrode system and thereby give an apparent increase in total BOD. Current studies indicate that the second factor is quite significant with certain types of organic wastes and biological systems. It is essential, therefore, that the materials used in the construction of an electrode system be relatively inert to biological oxidation.

Table 3

BOD Measurements by Standard Winkler and by Electrode Procedures

Sample No.	Series No.	Test Method	TIME IN DAYS 0	1	2	3	4	5	5 Days DO PPM	5 Days BOD PPM
			Dissolved Oxygen Concentration — PPM							
A	1	Winkler	7.6	6.6	5.5	4.0	3.2	2.7	4.9	245
		Electrode	7.6	6.4	5.2	3.6	2.6	2.2	5.4	270
B	1	Winkler	8.0	7.3	6.7	6.2	5.5	5.1	2.9	290
		Electrode	8.1	7.2	6.5	5.9	5.2	4.7	3.4	340
A	2	Winkler	8.0	6.1	3.9	2.5	1.6	1.2	6.8	227
		Electrode	7.8	5.7	4.0	2.2	1.3	0.8	7.0	233
B	2	Winkler	7.6	5.0	2.9	1.8	1.3	0.9	6.7	223
		Electrode	7.4	4.7	2.6	1.5	0.8	0.4	7.0	233
C	2	Winkler	7.6	7.0	5.9	5.1	4.2	3.3	4.3	215
		Electrode	7.7	6.9	5.7	4.7	3.9	2.9	4.8	240
D	2	Winkler	7.4	6.5	5.6	4.8	4.1	3.6	3.8	190
		Electrode	7.5	6.3	5.4	4.3	3.7	3.2	4.3	215
E	2	Winkler	7.8	6.5	4.9	3.7	2.9	2.3	5.5	275
		Electrode	7.9	6.4	4.6	3.3	2.6	1.9	6.0	300
A	3	Winkler	8.1	7.1	6.3	5.6	5.0	4.5	3.6	180
		Electrode	8.1	7.3	6.6	5.6	5.0	4.3	3.8	190
B	3	Winkler	8.0	6.8	5.9	5.0	4.4	3.9	4.1	205
		Electrode	8.1	6.7	5.7	5.1	4.1	3.6	4.5	225
A	4	Winkler	8.1	7.5	7.0	6.3	5.8	5.4	2.7	270
		Electrode	8.3	7.4	6.7	6.0	5.6	5.2	3.1	310
B	4	Winkler	7.8	6.5	5.2	4.2	3.4	2.7	5.1	255
		Electrode	7.6	6.5	5.3	4.0	3.1	2.4	5.2	260
A	5	Winkler	7.9	6.0	4.6	3.3	2.5	1.8	6.1	305
		Electrode	8.0	6.3	4.8	3.3	2.7	2.1	5.9	295
B	5	Winkler	7.8	6.2	4.6	3.5	2.4	1.9	5.8	290
		Electrode	7.7	6.0	4.2	3.2	2.2	1.6	6.1	305
A	6	Winkler	8.1	6.4	5.3	4.1	3.2	2.6	5.5	275
		Electrode	8.3	6.3	5.0	3.8	2.9	2.3	6.0	300
B	6	Winkler	7.7	6.6	5.5	4.5	3.7	3.0	4.7	235
		Electrode	7.6	6.2	5.2	4.1	3.2	2.5	5.1	255
A	7	Winkler	8.0	6.1	4.3	2.9	2.1	1.5	6.5	325
		Electrode	8.0	6.0	4.2	2.7	1.9	1.2	6.8	340
B	7	Winkler	7.7	6.6	4.5	3.0	2.5	1.9	5.8	290
		Electrode	7.7	6.3	4.3	3.1	2.6	2.0	5.7	285

Series No. 1 was conducted with continous stirring of the sample. The instrument was standardized before each DO reading. A new battery was used for each BOD test.

Series No. 2 was conducted with continuous stirring of the sample. The instrument was standardized before each BOD test and the same battery was used throughout all BOD tests in the series.

Series No. 3 was conducted with the sample stirred only for a 15-minute period preceding readings. The instrument was standardized only before the initial DO reading. A new battery was used for each BOD test.

Series No. 4 was conducted with the sample stirred only for 15-minute periods preceding readings. The instrument was calibrated before each BOD test. The same battery was used for all BOD tests in the series.

Series No. 5—same as No. 4 except that instrument was calibrated only before the initial BOD test.

Series No. 6 was conducted with continuous stirring of the samples. The instrument was calibrated only before the initial BOD test. The same battery was used for all BOD tests.

Series No. 7—same as No. 4 except that a new battery was used for each BOD test.

The studies designed to check the need for frequent standardization of the electrode system showed that no appreciable drift would occur for periods of 10 to 15 days of continuous operation. As indicated in an earlier section, aging of the battery is the main cause of zero-drift. Frequent standardization becomes necessary if reliable results are to be obtained with a battery nearing exhaustion. In general, if the battery is replaced every 10 to 15 days, standardization will be necessary only when a new battery is installed.

Summary and Conclusions

The reported study indicates the feasibility of employing a plastic covered, stationary, platinum-electrode system for measuring the dissolved oxygen and BOD content of water and domestic sewage. The fact that any number of points on the BOD versus time curve can be obtained from single samples is of great value in routine laboratory studies. The

electrode procedure also offers the possibility of running long-term BOD tests on a single sample of waste.

From the experimental work on the application of a plastic covered stationary electrode system for DO and BOD determinations, the following conclusions were reached:

1. The electrode gives reproducibility of dissolved oxygen measurements comparable to that of the standard chemical (Winkler) tests.

2. The electrode system response is temperature-dependent. Since all BOD work is carried out at a constant temperature, temperature compensation is not required.

3. The electrode cell will operate satisfactorily with either potassium hydroxide or potassium chloride, in varying concentrations, as an internal electrolyte.

4. Zero-drift of the electrode cell is caused primarily by changes in the battery. This effect can be eliminated by frequent standardization of the system or by replacing the battery every 10 to 15 days.

5. A particular electrode will usually give a stable output in less than three minutes when taken from one environment to another.

6. Dissolved oxygen concentrations can be determined with a degree of accuracy comparable to that of the standard Winkler test at a particular temperature, provided the temperature is held constant.

7. The polyethylene film is satisfactory as an electrode membrane, and is seldom a cause for electrode cell errors. Membranes three or four mils in thickness are the most satisfactory.

8. In general, a thorough rinsing of the electrode with distilled water at the end of each 5-day BOD test is sufficient for routine BOD work. A more thorough cleaning and removal of deposits from the electrode will be required three or four times a year.

9. Certain plastic components of the electrode cell used in this study can be oxidized by bacteria. It is necessary that this error in oxygen utilization be eliminated by the use of materials which are inert to biological oxidation.

10. The constituents of the domestic sewage used in this BOD study did not interfere with electrode operation for periods of five days.

11. With proper control of operating conditions, continuous BOD analysis of domestic sewage can be made with the plastic covered, stationary platinum-electrode system.

Acknowledgment

This research was supported in part by the Ohio River Valley Water Sanitation Commission and in part by a PHS research grant (RG-6614) from the National Institutes of Health, U. S. Public Health Service.

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The fundamentals are presented of the theory and applications of . . .

ORP Measurement in Waste Treatment*

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EDITOR'S NOTE: One of the more poorly understood and yet potentially useful determinations available to the waste treatment field is that for oxidation reduction potential (ORP). This measurement can be used for almost anything from sewage odor control to complete operation of an activated sludge plant. One major factor in the lack of understanding is the absence of a universally accepted convention for signs. The effect of this particular difference can easily be seen when it is appreciated that the sign for a given reaction potential in the handbook will be the opposite of that measured on an instrument when used with the same materials.

■ MANY INDUSTRIAL and all domestic wastes undergo chemical change from the point of origin to final disposal. This change usually consists of biological reduction, coupled with, but opposing some form of oxidation. In addition, deliberate oxidation or reduction processes are sometimes inserted to bring about an exceptable end product.

A waste rich in organic matter will decompose rapidly if the pH, temperature, and other variables involved permit. It could also be stated that such a waste rapidly becomes reduced. Conversely, this waste exposed to adequate aeration or strong chemical oxidants will be oxidized and will display chemical and physical characteristics completely unlike the reduced material. Activated sludge processes and oxidation ponds take advantage of the fact that organic wastes can be broken down into harmless inorganic chemicals by the proper maintenance of biological activity in conjunction with the introduction of oxygen. The source of the oxygen will depend on the process involved whether it be by chemical addition, algal growth, aeration, etc.

With inorganic chemical wastes certain toxic or unwanted compounds can be oxidized or reduced by the controlled addition of opposing reducing or oxidizing agents to produce harmless products.

A bibliography outlining the numerous processes and methods that already have been developed on this subject would indeed be a lengthy one. It can be stated on a qualified basis that each and every process, involving oxidation-reduction, can be analytically monitored by means of continuous ORP measurement. The qualifications sometimes required, however, tend to negate the practicality of some applications. In fact, the seemingly broad gap between that which theoretically can be done and what is realistically possible and practical represents the subject of this discussion. The usefulness of the measurement can only be evaluated by an understanding of its principles and limitations.

The Principles of ORP Measurement

Generally speaking, all chemical reactions involving an exchange of electrons are considered to be oxidation-reduction reactions. The relative strengths of the oxidant and reductant involved can be measured by determining the oxidation-reduction potential prevailing. This can be done by inserting an unattackable electrode, such as platinum, rhodium, etc., into the solution together with a constant voltage reference electrode and measuring the resulting emf by means of a high impedance potentiometer or similar device. The emf or voltage measured is the difference between the individual potentials developed at each electrode. If the reference electrode is a hydrogen gas electrode, the potential developed at the measuring electrode by convention can be considered the true potential of the oxidation-reduction reaction being measured. If a calomel or silver-silver chloride reference electrode or any other is employed, a correction factor must be incorporated. The details of this aspect will be discussed separately later in this paper.

The significance of this measurement relies on the fact that all compounds or materials that can exchange electrons develop specific potentials of a higher or lower magnitude than the arbitrary reference, namely, hydrogen. The following Table 1 illustrates some of the standard oxidation-reduction potentials that are pertinent to this discussion.[1] The values, in volts, referred to the Hydrogen-Hydrogen Ion Couple at zero volts are for Unit Activities and Temperature of 25°C. Designed as E_o, they can be inserted into the general form of the Nernst equation. To best understand the relationship between a measured ORP one might observe and the potential E_o that prevails under the terms of Table 1, the general form of the Nernst equation should be examined:

*This paper was originally presented before the Symposium on Industrial Wastes presented by the Division of Water and Waste Chemistry of the American Chemical Society at its 137th National Meeting in Cleveland April 11 and 12, 1960 and is printed here with the permission of ACS.

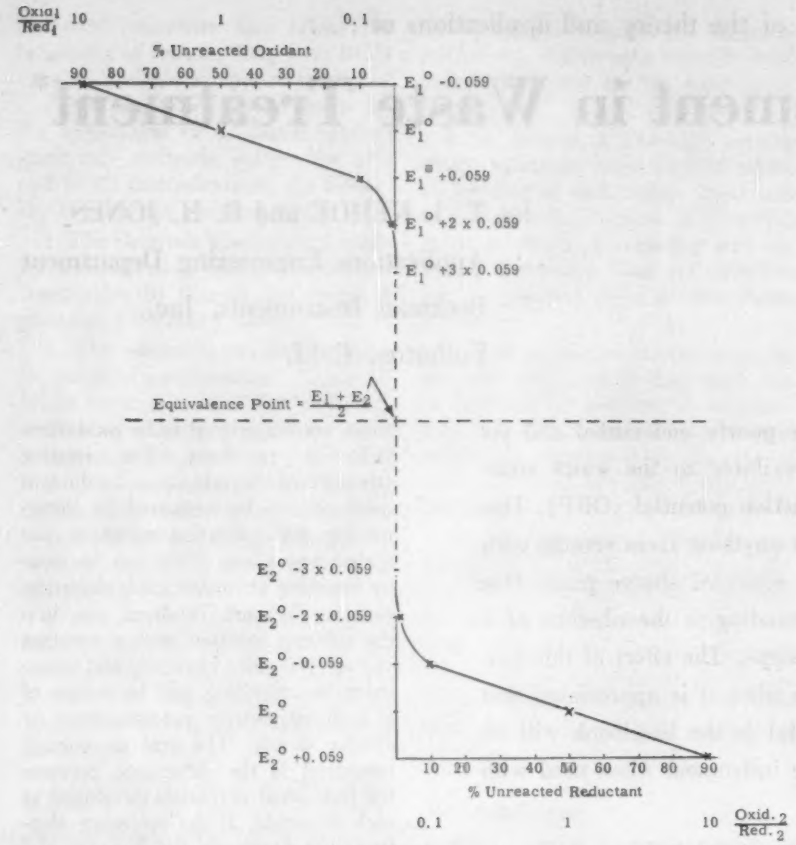


FIG 1. GENERALIZED POTENTIOMETER Titration Curve

$$E = E_o - \frac{0.0591}{n} \log \frac{\text{oxidant}}{\text{reductant}}$$

E = The measured emf expressed in volts opposed to the normal hydrogen electrode whose potential is zero.

E_o = The standard emf as found in the preceeding table and under the conditions as specified.

n = Number of electrons or electron equivalents involved in the reaction.

Table I
Potentials of Solutions at Unit Activity*

	E_o, volts
$CN^- + 2OH^- = CNO^- + H_2O + 2E^-$	+0.97
$Fe + 2OH^- = Fe(OH)_2 + 2E^-$	+0.86
$Fe(OH)_2 + OH^- = Fe(OH)_3 + E^-$	+0.65
$Cr = Cr^{++} + 2E^-$	+0.6
$S^{--} = S + 2E^-$	+0.51
$Fe = Fe^{++} + 2E^-$	+0.44
$Cr^{++} = Cr^{+++} + E^-$	+0.4
$H_2 = 2H^+ + 2E^-$	0.000
$HCN + H_2O = HCNO + 2H^+ + 2E^-$	0.0
$H_2S = S + 2H^+ + 2E^-$	−0.17
$S + 3H_2O = H_2SO_3 + 4H^+ + 2E^-$	−0.47
$Fe^{++} = Fe^{+++} + E^-$	−0.74
$2Cl^- = Cl_2 + 2E^-$	−1.359
$Cl^- + H_2O = HClO + H^+ + 2E^-$	−1.50

*Related to Hydrogen—Hydrogen Ion Couple at IATM and 25°C

From the above one can predict the expected potential depending upon the ratio of oxidant and reductant. The actual concentration of either oxidant or reductant cannot be determined by the electrode potential alone. This is a condition similar to pH measurement wherein the total acidity or alkalinity cannot be determined by the pH value alone. In both cases, a titration must be performed to quantitatively analyze the solution. Figure 1[2] illustrates the voltage change as an oxidant (Ox_1) is reduced by a reductant (Red_2) until an excess of reductant appears according to the following equation and applying the Nernst equation:

Sign Conventions in Electrochemistry

To understand and properly interpret the equations and handbook data on this subject, it is necessary to appreciate the rather confusing sign conventions that exist.

To designate the sign of the potential at a single electrode or half-cell potential, a universal convention has not yet been adopted. There are two systems which appear to be completely opposite and are referred to as the American Convention and the European Convention. The American Convention is illustrated in the previous Table 1. Here the sign of the potential is the true polarity of the solution surrounding the measuring electrode and not the opposite sign of the electrode itself. Instrument makers and many users are only concerned with the sign of the electrode since the meter is only aware of this polarity. Thus, most millivolt meters read out in signs following the European Convention.

The electrode potential by the European Convention becomes more negative as the agent becomes a more effective reductant than hydrogen and more positive if the agent is a more effective oxidant.

In expressing a complete cell reaction it has been generally agreed[3] that the emf is given a positive sign if the electrode on the left of the scheme is negative and that on the right is positive. Also, the cell reaction is always written as if oxidation always occurred at the left electrode and reduction at the right. Thus, a positive emf denotes that the cell reaction proceeds from left to right and a negative one in the reverse direction.

Reference Electrode Potential Corrections

The complete cell reaction potential includes the potential at or on the measuring electrode, the purpose of the measurement, together with the potential of the reference electrode.

Most data assumes that the reference is a hydrogen electrode in which case this potential arbitrarily is zero at all temperatures thus is of no concern. On the other hand, all ORP measurements employ either a calomel or silver-silver chloride electrode as a reference. Thus, a correction factor must be applied to the potential indicated on the meter to make the reading conform to handbook values.

This can be expressed by the following equation:

Eh = E + voltage of reference electrode

where Eh = The potential with reference to the hydrogen electrode

E = Observed voltage with calomel or silver-silver chloride

Potential of standard calomel reference electrode (with sat. KCl @ 25°C — European Conv.) +0.244 volts

Potential of silver-silver chloride reference electrode (with 4M KCl @ 25°C — European Conv.)	+0.199 volts
Potential of standard hydrogen electrode	0.00 volts

For example, if the saturated calomel electrode is used as the reference electrode, and the measured voltage E is 400 mv. Eh = 400 + 244 = 644 mv at 25°C (voltage of saturated calomel electrode is 244.3 mv at 25°C). If the measured value E is −544 mv then Eh = 544 + 244 = −300 mv at 25°C. It can be seen that the Eh of an oxidation-reduction system will always differ from the measured value E by the voltage difference between the reference electrode being used and a normal hydrogen electrode. The values given will be opposite to the signs appearing in the handbook. The same type of correction would apply if the silver-silver chloride electrode were employed in place of the calomel but differing by 45 millivolts (@ 25°C).

Limitations of ORP Measurement

From the preceeding it would appear that this method of measurement offers a positive means of controlling numerous reactions. In part, this is true. On the other hand, it is rare that domestic or individual wastes are simple wastes in respect to the organic and/or inorganic chemicals usually present.

In most cases, a platinum surface forms the measuring electrode in an ORP cell. The limitations of this electrode can include the following: 1) It can be influenced by all oxidants and reductants present. 2) The surface can become mechanically coated to desensitize its performance. 3) The surface can exhibit a memory effect by exposure to strong oxidants or reductants with subsequent residual influence, 4) The pH of the solution influences the net potential measured. Figure 2 illustrates the sizeable influence of pH as it appears in the classical hexavalent chromium reduction, 5) The temperature of the solution influences the potential but only slightly. The necessary correction will usually be less than 1 millivolt per degree centigrade. This value varies with the electrode being used. Temperature is much more significant as it affects the oxidation-reduction reaction rate since in most processes reaction rates accelerate with increasing temperature.

The influence of other oxidants and reductants, particularly in wastes, cannot be ignored. It would be extremely difficult if not impossible to account for and assess all of the oxidants and reductants found in domestic sewage as it reaches a treatment plant. Correlation between chlorination of treatment plant influent by ORP measurement and odor control through the plant offers interesting possibilities. The authors evaluated this method at several California treatment plants. It was found that sub-residual chlorination, to boost the ORP of the sewage to a slightly positive level assured odor-free operation. Depending upon pH, time of day, age, climate, etc., the incoming sewage had ORP levels ranging from −300 to +100 mv. Such a range is similar to that found by Eckenfelder and Hood[4], Eliassen[5], Grune et al.[6], and others. For those concerned, it is recommended that this work of Grune et al.[6] be reviewed in detail to appreciate the significance of ORP within sewage treatment processes. Eckenfelder and Hood[4] present data illustrating the influence of pH on the ORP of various industrial wastes.

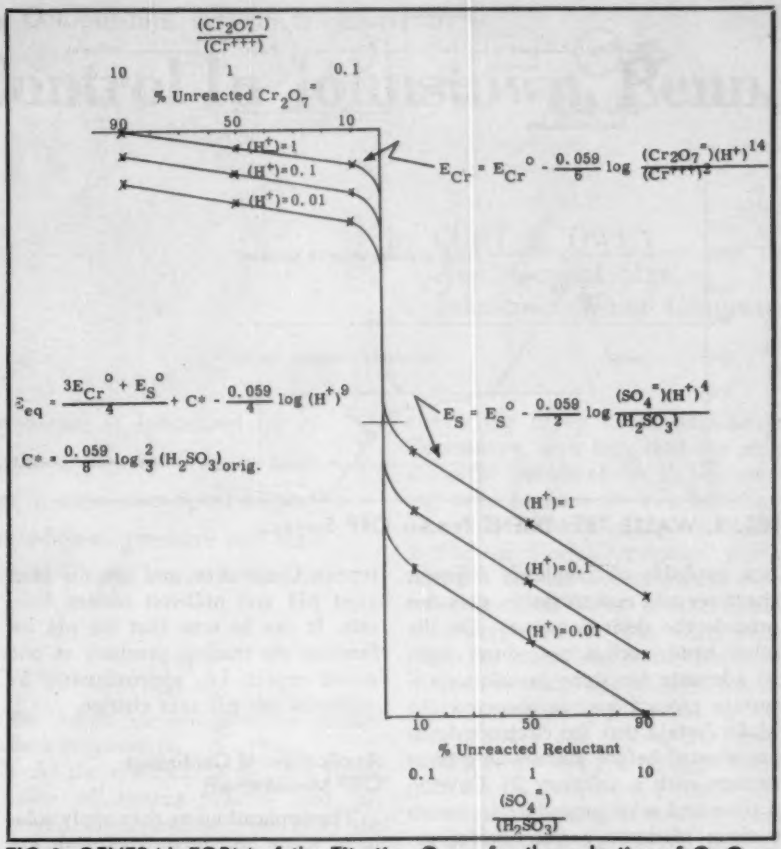


FIG 2. GENERAL FORM of the Titration Curve for the reduction of $Cr_2O_7^{=}$ with SO_2

They also point out the complexity of organic wastes and the variables that must be considered to obtain reliable information from an ORP measurement. Figure 3 from their work illustrates the general correlation of ORP to influence steps taken through a waste treatment plant. The wastes consisted of antibiotics in conjunction with domestic sewage.

Calibration of an ORP System

It is frequently suggested that some means be established to calibrate or standardize an ORP system. Unfortunately, because of the complexity of most measurements from the standpoint of multiplicity of variables, such a procedure might cause more harm than good. Also, mention was made earlier of memory or poisoning effects. In a continuous measurement, a platinum electrode can only measure the potential prevailing. It cannot deceive unless the surface becomes coated or ORP levels shift rapidly to introduce the memory problem. Taking an electrode pair from a stream and placing it into a beaker containing a "standard" ORP solu-

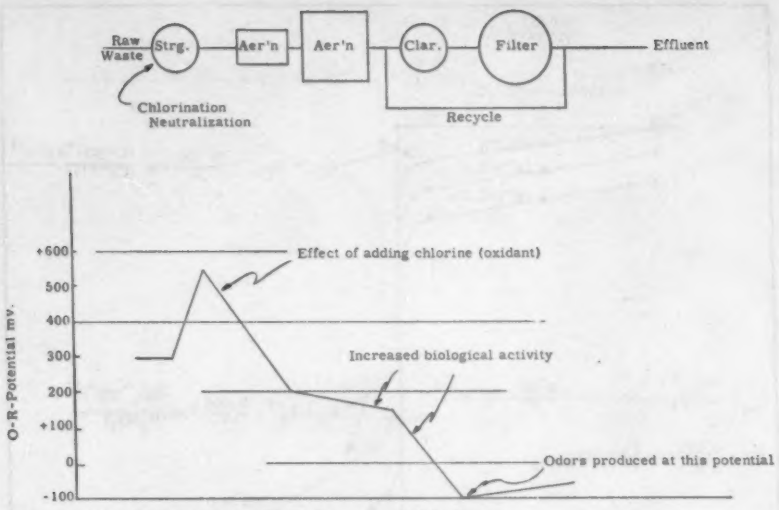


FIG. 3. WASTE TREATMENT Process ORP Survey.

tion, probably of completely different character and concentration, may not provide the desired answer. On the other hand, such a procedure might be adequate for some installations if certain precautions are observed: 1) Make certain that the electrode leads are shorted before withdrawing from contact with a solution, 2) Develop a rinse and wipe procedure to assure a clean platinum surface before attempting to calibrate. The extent of this step will depend upon the nature of the stream and electrode condition upon removal, 3) Calibrate in two "standard" solutions making sure that a non-drifting final measurement is attained.

The most frequently suggested solutions for checking the electrodes consist of quinhydrone in buffers. The potential of a quinhydrone solution in 4.0 and 7.0 pH buffer may be calculated. The solutions can be prepared simply by adding a few grams of quinhydrone to standard buffer solution. The solutions should be prepared fresh for each use. Values are given in Table 2 for the temperatures 20, 25, and 30°C are for the calomel, silver-silver chloride, and hydrogen reference electrodes in both buffers. These readings in Table 2 are European Convention and are the ones most pH and millivolt meters indicate. It can be seen that the pH influences the reading precisely as one would expect, i.e., approximately 59 millivolts per pH unit change.

Applications of Continuous ORP Measurement

The applications as they apply solely to waste and waste treatment are numerous. As already discussed, the practicality of each application must be closely scrutinized and will depend upon the need, interferences, maintenance problems, etc. There are excellent references that discuss the ORP applications in sewage treatment plants. A few of these references already have been cited. The most interesting of this group of applications involve the following: 1) Treatment plant odor control, 2) Aeration control sludge processes, 3) Digester monitoring, 4) Influent monitoring to detect unwanted industrial waste reductants or oxidants.

In the area of industrial waste treatment, the two most significant processes that practically demand employment of ORP are the cyanide oxidation and the hexavalent chromate reduction processes.

In the general field of inorganic chemical wastes, there are a variety of specialized wastes where unwanted oxidants or reductants are involved.

In the food, pharmaceutical, diary, and organic chemical industries, a general application exists primarily concerning high BOD organic wastes. The limitations and problems already discussed regarding sewage applications apply here as well. A great amount of study has been made in the pharmaceutical industry. Here, their problems are magnified since the nature of some of their wastes can retard or kill the biological oxidation or reduction processes necessary for proper waste treatment either at the source or in domestic treatment plants. ORP measurement can serve to assure that the optimum conditions are maintained.

Summary

In conclusion, it is urged that those directly concerned with this measurement condense the basic information on this subject into an understandable form for direct use. Much of the confusion regarding ORP concerns the sign convention. The limitations of the measurement must be recognized and each application and/or installation must be investigated with this in mind. A means of attaining reliability assurance must be established. Checking the electrode pair against quinhydrone solutions is one measure that can be employed. The ORP measurement is influenced by all oxidants and reductants. Thus, it is rare that this measurement can be considered a specific measurement. As a result high measurement accuracy cannot be expected. ORP is not quantitative measurement but only conveys oxidation-reduction ratios. The applications generally concern organic wastes of an industrial or domestic nature.

Table 2

ORP of Quinhydrone Solutions

	pH 4			pH 7		
Temperature, °C	20°	25°	30°	20°	25°	30°
Calomel	223	218	213	47	41	34
Silver-Silver Chloride	268	263	258	92	86	79
Hydrogen	470	462	454	295	285	275

References

1 From Latimer and Hilderbrand, *Reference Book of Inorganic Chemistry*, The Macmillan Co., 1951.
2 Adopted from Kolthoff and Furman, *Potentometric Titrations*, John Wiley and Sons, Inc., New York, 1931.
3 Bates, R. G., *Electrometric pH Determinations*, John Wiley and Sons, Inc. New York 1954.
4 Eckenfelder, W. W. Jr., and Hood, J. W., p. 221, *Proc. of the Sixth Ind. Waste Conf.*, Purdue Univ., 1951.
5 Eliassen, Rolf, *Water & Sewage Work—Ref. & Data Edition*, p. 211, 1945.
6 Grune, W. N., et al., p. 604, *Proc. of the Twelfth Ind. Waste Conf.*, Purdue University, 1957.

Control of remote facilities in Octopus-like system is solved by . . .

Supervisory Control In Johnstown, Penn.

by CURT E. OWEN
Asst. General Mgr.
Johnstown Water Company

RESUME: Solution of operating problems at Johnstown by installing centralized supervisory equipment has resulted in more dependable water service and savings in man-hours spent inspecting and checking. Utilizing telemetered flow, pressure and tank level data, one man operates valves and pumps remotely to control the complex system.

■ THE JOHNSTOWN WATER supply system is spread out over 38 square miles of hilly terrain, and manual control of the many elevated tanks, valves and pumps was very difficult. The system was kept under partial control by the time-consuming method of continual manual inspection. Because inspections could only be periodic, electrical and mechanical problems of valves and pumps could develop without immediate detection. If a valve did stick or a pump remained out of operation for very long, the section of the water system involved could be out of water. Many hours of work would be needed to bleed the line of air and place the section back in operation.

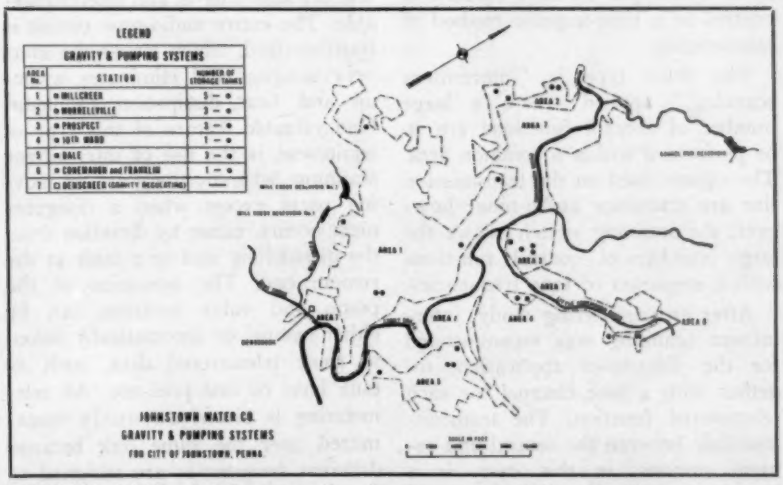
As the system enlarged, the possibility of system failures also enlarged; therefore, early in 1957, the Johnstown Water Company, in an effort to eliminate their system maintenance problems, seriously investigated the use of centralized control.

Historical Development of Johnstown, Pennsylvania

The City of Johnstown, Pennsylvania is situated in the Allegheny Mountains in the shape of a Y formed by the confluence of two rivers, the Stony Creek and Little Conemaugh, with hilly land not only along the outside of the Y, but coming down between the two branches. The chief industry is a plant of the Bethlehem Steel Corporation which stretches out for approximately nine miles on both sides of the Little Conemaugh River. The chief railroad, the main line of the Pennsylvania Railroad, approaches Johnstown through a gap formed by the base of the Y and follows the Conemaugh River straight through town.

In the old days, when a community water supply was first needed, some of the more progressive citizens formed a company and dammed up one of the mountain streams and piped the water from there into town simply by gravity. When the city grew to the point where additional supply was needed, another stream was dammed and more mountain water was fed in. This continued until, at the present time, Johnstown is supplied by five dams; three dams along the branch of the Y, one from the base of the Y, and the other from the other branch of the Y. While this was going on, the people in the city began to form communities on top of the hills in the outskirts of town, staying close to the town at first and expanding further back as time went on.

These residential sections turned out to be higher than the dams; consequently, pumping was necessary. As one hill was settled, a pumping station was built, a tank was erected, and the people were supplied with water. Continual growth and the migration of people to the hills went on until the Johnstown Water Company consisted of the five abovementioned dams, six different pumping stations, sixteen tanks—in many cases one being fed from the other—


LEGEND
GRAVITY & PUMPING SYSTEMS
AREA No.
STATION
NUMBER OF STORAGE TANKS
1 ○ MILLCREEK 5 — ●
2 ○ WOODVILLE 3 — ●
3 ○ PROSPECT 3 — ●
4 ○ 10TH WARD 1 — ●
5 ○ DALE 3 — ●
6 ○ CONEMAUGH and FRANKLIN 1 — ●
7 □ BENSCREEK (GRAVITY REGULATING) —
JOHNSTOWN WATER CO.
GRAVITY & PUMPING SYSTEMS
FOR CITY OF JOHNSTOWN, PENNA.

OVERALL MAP of Johnstown, Pa. showing major station locations.

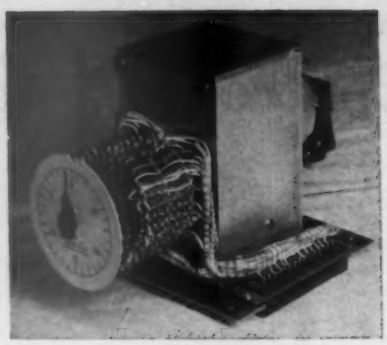
and twenty pressure reducing valves. Fig 1. The Johnstown Water Company not only supplies the City of Johnstown, but all or part of thirteen additional residential sections. One can see from this that, although the company is not particularly large, it is built somewhat similar to an octopus, going out in many directions.

The company supplies 25,000 consumers with approximately 13,000,000 gallons of water per day. The industrial consumers are fed mostly by gravity, and although 40 per cent of the consumers are on one pumping system or another, it is necessary to pump at the most 2,500,000 gallons of water per day. The hilly terrain causes parts of the central part of the city to be as low as 1,100 feet in elevation, the dams between 1,400 and 1,500 feet in elevation, and some of the residential sections as high as 1,900 feet in elevation. The stations, as the crow flies, are perhaps not farther than seven miles in distance, but it is quite often necessary to travel twenty-five miles to get there. The water system covers an area of 38 square miles.

Before the inauguration of centralized control, it was necessary to check the pumps and valves daily; and the tanks at least once a week, if not more often. Many of these are in locations which are very hard to reach, especially in winter weather. Then too, as mentioned before, altitude valves and pressure regulators had a bad habit of ceasing to operate several hours after having been checked. How much time was spent in this checking procedure, and how much time was spent in bleeding air from the lines because one went dry, would be impossible to determine. Even worse, one cannot put a cost on disgruntled consumers. Supervisory control was an ideal method to regulate the requirements of this far-flung system.

Johnstown's Supervisory Control System

Because each water system is different, a particular engineering approach to supervisory control is required. B-I-F Industries, Inc., was selected to give this system-package because they offered custom engineering, manufacturing and service which best suited the Johnstown situation.



SCANNING switch of the type used at Johnstown. Master switch is located in central control station panel and slave switches operate synchronously at each remote station.

Of the three different types of control equipment available offering the most economical and reliable method to control and telemeter the information for each supervisory control system, the simplest form is "two-function", which allows two signals, either control or telemetering, to be sent simultaneously in the same or opposite directions. This equipment is used primarily when a leg of the system warrants only two signals, such as "on-off" control and report back of an isolated pump.

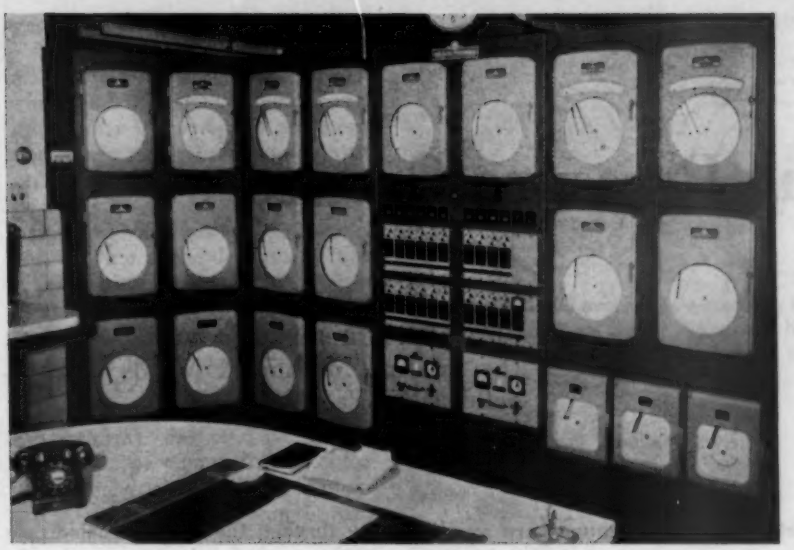
The next type is "transistor audio tone," employed for transmitting a large number of functions of control or telemetering simultaneously over the same transmission link. This is more applicable where the functions are spread out radially or in a long line. The absence or presence of a fixed tone frequency (normally between 300 cycles per second and 3,000 cycles per second) constitutes control or a time-impulse method of telemetering.

The third type is "intermittent scanning," applied where a large number of control functions are to be performed within a common area. The signals used on the transmission line are transistor audio-tone; however, the scanning switch allows the large number of control functions with a minimum of tone frequencies.

After an engineering study, intermittent scanning was recommended for the Johnstown application, together with a tone channel for each telemetered function. The transmission link between the central and remote stations, in this case, is a leased telephone line. However, the signals can be transmitted over private wires, micro-wave, carrier or radio bands, as well as the leased telephone lines. The use of each again depends upon the specific application.

The heart of the intermittent scanning system is the scanning switch, one at the dispatching end and each controlled remote station. If a remote pump is to be started, the operator turns a selector switch to "on." This creates a disagreement with the existing conditions and starts turning the scanning switches, Fig 2. As they turn, they pass over control and reportback contacts, and when they reach the contact which is linked to the pump switch "on", the control tone frequency is transmitted. At the remote station, a slave scanning switch turns in sychronization with the master scanner, and as the proper contact is reached, the transmitted control tone is received and the pump is turned on. A separate contact of the scanning switch reports back the operation of the pump through a different tone. Once the pump is reported back "on", the disagreement light goes off and the scanning switch comes to zero position and stops. Basically, fourteen controlled devices, turning a pump on or off, or opening or closing a valve, can be controlled by a scanning system in one revolution. In addition to control and telemetering, power failure and other alarm monitoring information are also reported to the central station.

The control switches are all of the plug-in type, making replacement quite easy. All the relays in the system are also plug-in and interchangeable. The entire audio-tone circuit is transistorized, which makes the units very compact and eliminates warm-up and heat dissipation problems. One valuable feature of this type of equipment is the use of intermittent scanning, whereby there are no moving parts except when a disagreement occurs, either by direction from the dispatching end or a fault at the remote end. The operation of the pump and valve switches can be either manual or automatically linked to some telemetered data, such as tank level or line pressure. All telemetering is simultaneously transmitted over the same link because different frequencies are assigned to each telemeter function.



SUPERVISORY control panel installed in Benscreek gravity regulating station. Recorders may be seen surrounding the various function control switches.

Supervisory Control at Johnstown, Pennsylvania

The system to be controlled at Johnstown consists of six pumping stations (Franklin, Morrellville, Dale, Millcreek, Tenth Ward and Prospect) and sixteen elevated tanks (Franklin, Morrellville, Tenth Ward, Dale, Roxbury, Millcreek, Prospect and Moxham), see system map, Fig 1. This system is all controlled from the panel shown in Figure 3, located in the Benscreek Regulating Station. Thirty separate pieces of information are telemetered to this board: five flows, sixteen pressures, and nine tank levels. In addition, ten pumps can be turned on or off, ten valves can be opened or closed, one valve controlled and its position indicated, all from the central control point. Finally, each pump has its total running time recorded, all tank level meters have a high level alarm, all six pumping stations have a power failure light, and there is an alarm silencer push button. It is easily seen how one man could completely control this system from this centralized point.

In Figure 3, ten pump controls are in the top row in the center section, the corresponding level valve controls are in the second or bottom row. Each of the six pumping stations has two pumps and two valves to control. Room for three future controls is available. This installation has two scanning systems—the left one controls the six pumps and six valves at the Morrellville, Dale and Millcreek stations, while the right one controls the four pumps and four valves at the Prospect and Franklin stations.

Summary

The use of transistor tone and synchronized scanning equipment made possible a centralized control station from which the different pump stations could be remotely operated. It made possible the transmitting of different tank levels to this one location, and it has made possible the transmitting of pressure showing whether reducing valves are working or not. Having this information in one central point has enabled the water company to claim that not one section has been out of water or dangerously low since its installation. It is calculated that savings will pay for the equipment, plus the total installation cost, in less than three years. The time saved in checking, and increased good will of the consumers, is all gravy—how rich will never be known. A completely integrated system from one manufacturer was definitely advantageous in this job application.

Selection and use of . . .

Dial Indicating Pressure Gauges

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EDITOR'S NOTE: A wide variety of pressure gauges are available for water works use. Important among these are dial indicating gauges of the bourdon tube type for pressure measurements in the range of 30 inches of Hg vacuum to 10,000 psi. This article will guide the engineer in selecting the proper gauges for his plant.

■ IN WATER SYSTEMS, good performance frequently depends upon existing pressures or pressure changes. To assure proper operation, the correct pressure gauge must be selected. In addition, proper gauge selection can prevent excessive water loss as happens, for example, when a distribution line breaks. A gauge that lacks the necessary degree of accuracy may not show this loss, particularly if the break occurs some distance from the pumping station. An accurate gauge, on the other hand, will indicate this drop in pressure almost at once.

This discussion deals with dial indicating gauges of the bourdon-tube type used for pressure measurements in the range of 30 inches of Hg vacuum to 10,000 psi. The objective is to give the engineer information and characteristics that are helpful as well as necessary for proper gauge selection.

Selection Factors

The following paragraphs discuss the more important factors which should be considered in selecting the right gauge.

Wear Conditions

Pulsating pressures, sudden shocks, and gauge vibration can seriously affect gauge accuracy and life. The ASA definition of pulsating pressure is similar to that for fluctuating pressure but is differentiated as having a cyclic regularity of variation. Rapid pulsations cause the gauge pointer to oscillate to the point that it is almost impossible to take a reading. In addition, they can cause excessive wear of the gauge mechanism and destroy gauge accuracy.

The simplest way to minimize the effects of pulsating pressure is to place a shut-off valve in the line to the gauge and throttle the valve until the pulsation just disappears. This method, however, invites trouble due to clogging of the very small opening through the valve. Reliable protection against pulsations can be obtained by using a pulsation dampener on the gauge. A typical type, Fig. 1, employs a throttling orifice screw which can be added to the gauge socket, or a porous metal disc, with a series of orifices which can absorb pulsations in excess of 1 cps. Such damping devices also prevent damage to the gauge from sudden and large pressure changes.

Gauge Connections

The basic types of gauge connections are discussed under Gauge Components. Where connections other than the standard 0.25 or 0.5 inch male connections are required, adapters are available.

If the gauge is installed so that a liquid column will exert a pressure due to the static head of liquid, correction must be made by a zero adjustment on the gauge pointer. This adjustment is made with the connecting piping full of liquid and the

Fig. 1. PULSATION DAMPENERS protect gauge elements from harmful variations in pressure buildups. Dampener, left, employs a throttling orifice screw which can be added to the gauge socket. A porous metal disc, right, absorbs pulsations in excess of 1 cps.

pressure source shut off. Normally a shut-off valve should be installed in the line between the pressure source and the liquid column. Static heads occur when liquids are measured, when gages or vapors contain condensables, or when corrosion seals are used.

Gauges should always be installed with the face of the dial in a vertical position with the midscale point in a perpendicular line with the bottom of the gauge. This is the position in which gauges are calibrated and designed to operate. In other positions, weight of the parts may affect wear and influence the readings. If the gauge is to be mounted in other positions, the position should be specified so that the gauge can be calibrated under operating conditions.

Gauge Size

The nominal size of the gauge is the inside diameter of the case at the face of the dial. Available gauge sizes depend somewhat on the type of gauge, and are generally related to the degree of accuracy required.

For drawn-case gauges, selection is usually limited to dial sizes of 1.5, 2, 2.5, 3.5 and 4.5 inches. In all of these sizes for a given range, the value of the smallest graduation is the same, as established by ASA standards.

Readability and accuracy do not basically influence the selection of drawn-case gauge sizes. However, relatively large numerals on large size dials do ease the readability where, for example, there are physical limits on how close the observer can approach the gauge to read it.

For Grade A and Grade AA gauges, commonly available in sizes over 4.5 inches, the values of the smallest graduations do vary somewhat with size. In general, gauges 8.5 inches and smaller have one set of limits and gauges larger than 8.5 inches have another. These values are closely related to the guaranteed accuracies of the gauges.

Little is gained by insisting on finer gauge graduations that are compatible with the accuracy of the gauge. For example, with a Grade B gauge (2 per cent accuracy over midscale) which has a range of 0 to 600 psi, readings accurate to within 12 psi of the true value can be obtained. However, actual minor graduation limits for this range are 10 psi. To specify smaller divisions would mislead persons reading the gauge.

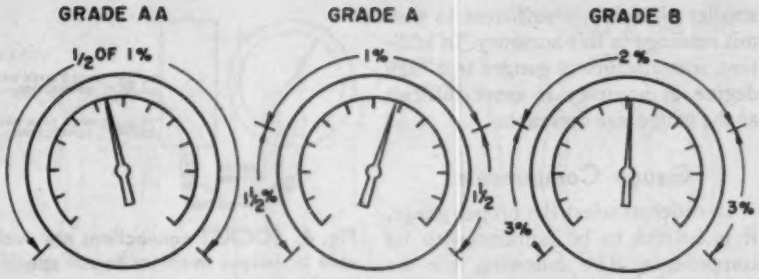

Fig. 2. GAUGE accuracies according to American Stand Classifications. For example, a 600 psi Grade AA gauge has an accuracy within 3 psi. Grade A and B gauges have one accuracy for middle half of scale; another accuracy for the remainder of scale.

Accuracy Required

Accuracy is generally expressed in terms of per cent of total scale range. It should never simply be expressed in per cent without the qualification.

The degree of accuracy specified depends upon the conditions of service, actual need for precise readings versus trend indications, and probable maintenance care to sustain the accuracy. As a general rule, the more rugged the service, the greater the compromise between accuracy and costs.

An often misunderstood aspect of stated gauge accuracies is the fact that the degree of error is the maximum guaranteed by the manufacturer. This means that the gauge will not exceed an error of, for example, 2 per cent of scale range. The actual accuracy may well be better than this value at working pressure. The gauge can be calibrated to determine the actual accuracy. However, such calibrations do not assure sustained accuracy.

Related to accuracy is the characteristic of reproducibility or consistency of readings. This is the ability of the gauge to give the same reading for the same applied pressure time after time. Consistency may be more important than the actual accuracy if the only purpose of the gauge is to tell an operator when to push a button or shut off a machine.

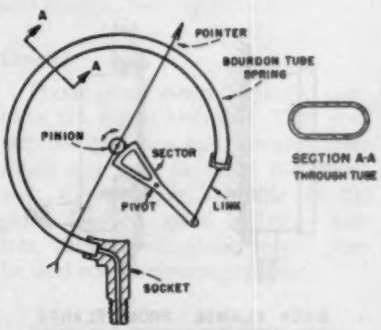

Fig. 3. CONSTRUCTION of typical bourdon-tube pressure gage. Selection of right gauge depends upon the accuracy, strength, and corrosion resistance of components.

Types of Dial Gauges

A knowledge of gauge classification is important in selecting the proper gauge initially and in the replacement of gauges. As will be seen, gauges are most commonly classified according to accuracy.

General Classifications

Pressure gauges are commonly classified according to accuracy (by ASA Standards), case style, and end use. Specific properties of each gauge type are given in Gauge Classification Methods.

The American Standard Indicating Pressure and Vacuum Gauges, B40.1-1939 (reaffirmed 1953), contains common gauge terminology and is widely used for gauge classification. This standard covers basic gauge definitions and specifications and establishes accuracy limitations for the various gauge classifications, Fig. 2.

Classifications of gauges by ASA standard accuracies automatically affects other gauge specifications. For example, Grade AA gauges of accuracy of 0.5 per cent of total scale range are not generally offered in dial sizes smaller than 4.5 inches diameter, since the readability of

smaller sizes is not sufficient to permit readings to this accuracy. In addition, manufacture of gauges to a high degree of accuracy is more difficult as the gauge size decreases.

Gauge Components

In order to select the proper gauge, it is helpful to be familiar with its components. The following are for the commonly used Bourdon-tube gauge as shown in Fig. 3: sockets, bourdon-tube springs, tube linkage, movement, pointer, dial, case, ring and crystal.

Sockets

The socket functions as a means of connecting the gauge to the pressure source. Generally, the socket provides support for all the other gauge components. Three distinct socket types are used in Bourdon-tube gauges: Bar stock, forged and cast.

For connection to the pressure source, most sockets have the Standard male connection with 0.25 or 0.5 inch National Pipe Threads. Other types of connections include female, machine threaded, alligator or hose, flare fitted, Dryseal threaded, and high-pressure threaded.

Socket connections extend from the case in various positions depending on application. The most commonly used types are low male, low-back male, and center-back male connections (see Fig. 4). Other special variations include top-connected and right or left hand connected. Back connections are generally suited for panel mounting while other connections are for mounting on pipes or equipment.

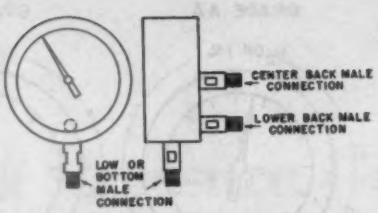

Fig. 4. SOCKET connections are available in various positions to suit specific applications.

Bourdon-tube Springs

The most critical component of the gauge is the bourdon-tube spring. This is a metal tube bent in a segment of a circle. One end of the tube is fastened to a socket which connects to the pressure source. The free end is sealed with a tip connected to the tube by soldering or welding, or by a combination of threading and soldering or welding. The tube must meet a number of stringent requirements. For continued performance, the user must select the gauge with the right tube by considering the nature of the fluid being measured, pressure range, overpressure, shock or vibration conditions and pulsating pressures.

Tube Linkage

The Bourdon-tube is connected to the gauge movement at its tip by means of a link arrangement. The type of connection required depends upon the temperature and pressures to which the gauge is subjected.

Movements

The motion of the Bourdon-tube's free end is multiplied by the movement and changed into circular motion. A small arc movement of the Bourdon tube repeatedly positions the gauge pointer over a 270° arc movement on the indicating dial.

Two plates with separating columns or posts form the cage of the movement. Within these plates are the shafts which carry the pinion and sector. The sector has a tail to which is attached the link from the Bourdon-tube tip.

Attached to the pinion, which meshes with the sector gear teeth, is a hairspring with the other end attached to a column. The spring provides tension on the pinion to reduce backlash and keep all clearances in one direction.

Materials used at points of contact are chosen to increase life and decrease wear between mating parts.

Pointers

The gauge reading is indicated on the graduated dial by the pointer. Weight and shape of the pointer affect the accuracy of the instrument and the precision of the reading.

The pointer mounts on the shaft which carries the pinion of the movement. There are several methods of mounting the pointer, each with a different degree of adjustability.

The shape of the pointer is usually compatible with the accuracy of the dial.

Dials

One of the most common dial forms consists of a metal plate coated with a background color, usually white. Graduations are printed on the coated metal. In another type

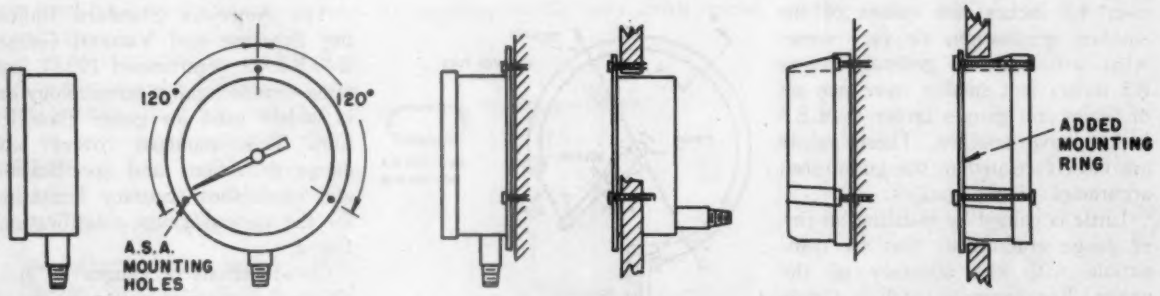

Fig. 5. MOUNTING STYLES for various gauge cases. (C) and (E) are generally wall mounted. Front-flange type is panel mounted. Beaded case is stem mounted. Turret style may be flush mounted with adapter ring.

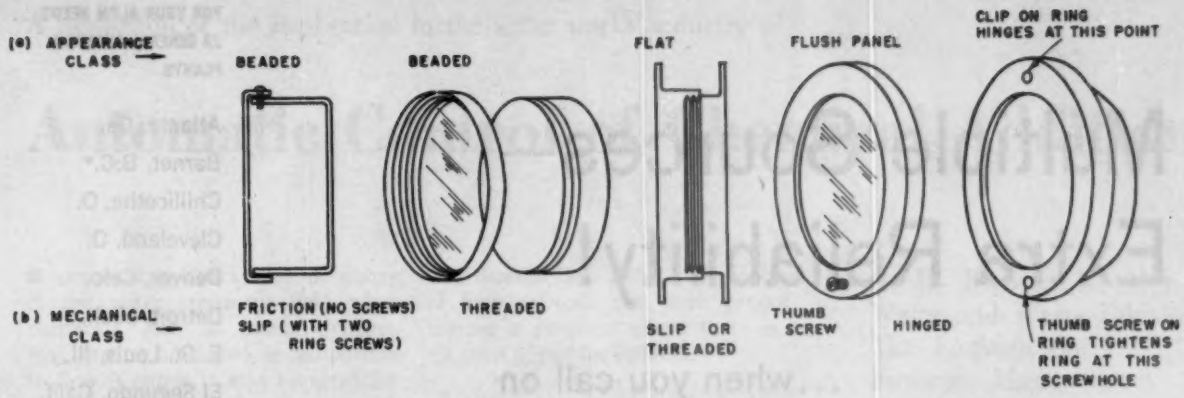

Fig. 6. HOLDING RINGS for crystals are classified by apperance and mechanical means of attachment.

the graduations are printed on white plastic and a thin layer of clear plastic is applied for protection. For readings of extreme precision, a mirrored strip around the scale eliminates parallax errors, and a pointer tip with a knife edge is used.

As an aid in selecting the right gauge or replacement part, a legend which gives the gauge model number and materials used in constructing the movement, connection, and Bourdon tube is printed on the dials of some of the larger gauges.

The dial scale is usually graduated over a 270° arc which gives a relatively long scale length for the dial diameter. The scale length contributes to readability. The number of graduations usually increases with the accuracy of the gauge, since there is little point in reading values which are more accurate than the gauge itself.

Cases

The gauge case encloses the gauge internals and protects working parts from dust, dirt, and in some designs from corrosive atmospheres. In addition, the gauge is often mounted on an instrument panel-board, wall, or machine by the case. If a gauge is stem mounted, the socket itself supports the gauge.

For safety reasons, a solid front wall may be required on the gauge to separate the observer from the gauge components. This is especially true on pneumatic applications. Such a wall is usually cast as an integral part of the case, and a weather-tight rubber disc seals the rear section, releasing pressure out the back of the gauge if the tube ruptures.

Drawn and cast cases are available in several different mounting styles. Gauges can be obtained with flanges on either the back or front of the case and with mounting holes located in accordance with ASA standards (Fig. 5). The back-flange style is used for wall or equipment mounting; the front-flange type for flush mounting on a panel.

Drawn-case gauges with beaded cases have no flange, and are stem-mounted. Cast cases are not normally available in this style, hence, a back-flange cast case for stem mounting must be specified.

The turret style is used primarily for wall mounting, but can be obtained with an adapter ring for flush mounting.

Rings

Gauge crystals are held against the case front by rings which are classified broadly into two categories: according to appearance, such as beaded, flat, flared, and peaked; and according to methods of attachment to the case, such as friction, slip, threaded, and hinged (See Fig. 6).

Crystals

Transparent cover crystals complete the gauge assembly. They protect the dial face and pointers from abuse and help to effect the gauge seal. Crystals are available in flat glass, beveled glass, cellulose acetate, shatterproof glass, acrylic plastic, and non-electrostatic plastic.

Other Measuring Elements

In addition to the Bourdon-tube, there are other measuring elements which are particularly suited to those applications requiring higher accuracy at lower pressures. The use of diaphragm capsules as pressure sensing devices where pressures are below 15 psi has long been recognized as one of the best methods of detecting low pressures. The following terms are used to define performance of diaphragm elements:

Travel

The maximum amount of travel that can be obtained will vary with respect to material thickness and diaphragm plate diameter. This can be increased by using additional diaphragm elements or by some sacrifice in linearity and hysteresis. If a high degree of linearity and repeatability is desired, the travel of the individual elements should be kept at a minimum.

Linearity

The linearity of a diaphragm capsule is the relationship between the pressure and motion expressed as a percentage deviation from the best straight line. Generally speaking, the greater the amount of motion required from a given capsule, the poorer the linearity.

Materials

Diaphragm capsules are made from beryllium copper, phosphor bronze, Ni-Span "C", stainless steel and other alloys.

Evacuated Capsules

Where measurements in terms of absolute pressure are desired, it is frequently necessary to provide evacuated capsules. Pressure to be measured is then applied to the outside of the capsule.

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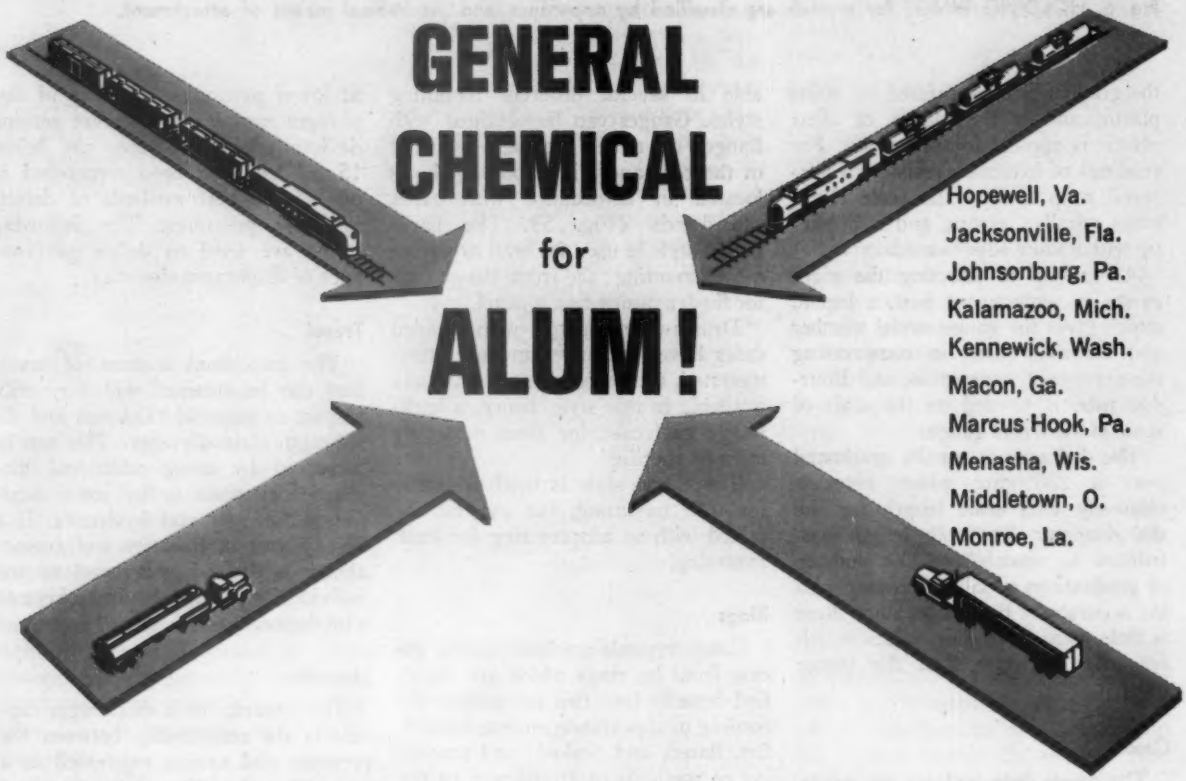

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A discussion of the application in the water works industry of . . .

Automatic Control of Chemical Addition

by R. H. BABCOCK, Mgr.
Water and Waste Division
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Foxboro, Mass.

■ AUTOMATIC CONTROL is necessary in the water treatment field when chemicals such as alum, chlorine, etc., are to be added in proportion to flow. Control is also required for the correction of concentrations such as pH, fluoride, and chlorine. Both of these requirements are very important in today's water treatment plants which, in many instances, are operated at varying flow rates. While it is possible to manually control the feeders which operate on this type of schedule, it is not in the real sense of the word practical. Many of these functions cannot be carried out with the manpower normally available in a water treatment plant. The result is that automatic control of chemical addition must be applied in varying degrees to almost all modern water treatment plants.

Two basic types of control are used: the so-called open loop and the closed loop. Open loop is typified by the usual method of setting a chemical feeder in proportion to flow rate, the feeder being operated by a signal from a water flow meter with no actual measurement of the amount of chemical being fed. The accuracy of this system depends entirely upon the accuracy of the feeder and its controls. The second type, closed loop, is typified by a liquid alum flow system where transmitting measurement equipment is used. In this system, an actual measurement is made of the quantity of alum being fed. This is compared against a desired quantity of alum and corrections continuously made to hold the actual quantity equal to the desired quantity. This control technique provides a high degree of accuracy.

By and large, most of the automatic control problems concern addition of chemicals in proportion to flow, the normal way in which coagulants, activated carbon, chlorine and fluorine are added. In the case of lime or soda ash, such proportioning is practical where there is a constant pH of the influent.

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Open Loop Control

The most common method of addition in proportion to flow is open loop control, with the impulse duration type most widely used. Impulse duration control is applicable to dry feeders of both the volumetric and gravimetric type, to chlorinators of all types, and to positive displacement metering pumps. Although, for practical purposes, it is universally applicable, it is not always the wisest choice when all factors are considered. Impulse duration control is based on a cam contacting mechanism, which operates in the manner illustrated by Fig 1. The contactor is positioned by a sensing element and is operated in conjunction with a cam turning at a constant rate. Cam cycles for chemical feeder control range from 12 seconds to 60 seconds per cycle. One type of contactor rides under the cam at the beginning of the cycle and there is no signal. When it leaves the trailing edge of the cam, the signal starts and continues until the leading edge of the cam is again encountered, at which time the cycle repeats itself. The result is that at 50 per cent of scale on a 12-second cycle, electrical contact is made during the last six seconds of the cycle. This type of control does not depend upon signal level but only signal duration. It is basically the way integrators or flow totalizers operate.

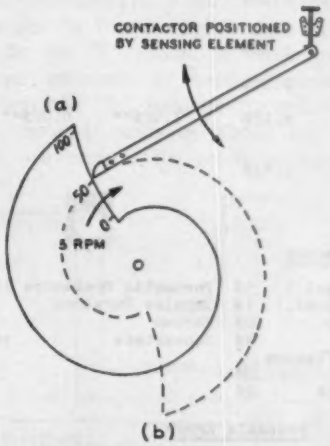

FIG 1 CONTACTOR for impulse duration control

Most impulse duration controllers are conventional integrating flow meters with an additional relay to carry the electrical load of the starting equipment for the feeder. Fig 2 illustrates the type of signal in impulse duration control. The upper half of the figure illustrates a hypothetical case in which flow actually makes stepwise changes, each of which is one cycle in duration. The total flow, or the area under the flow curve, is equal to the area under the impulse duration curve; therefore, 100 per cent accuracy is being achieved. In the lower part of the figure, the flow curve is changing linearly over both a 1 and 2 cycle period. There is no difference between the integrated area under the flow curve and under the pulse curve. In the long run, very small errors will be occurring between the impulse duration signal and the actual flow measurement. The instantaneous pulse will be in error from the flow but will normally average out over a period of time.

The advantage of impulse duration control is that a relatively inexpensive flow meter is adequate for the job. In many cases it has been suggested to engineers that if there is any possibility of needing feeder control in the future, the flow meters should be purchased with impulse duration units built into them. Since it is merely a matter of adding a

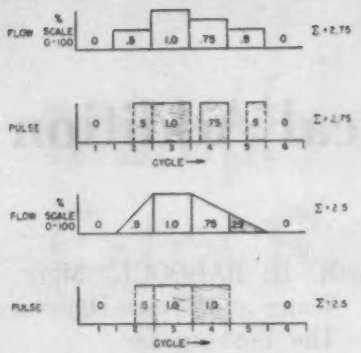

FIG 2 RELATIONSHIP OF FLOW to totalized (integrated) impulse duration signal (open loop control)

relay during manufacture of the conventional integrating flow meter, the expense is small. Once this equipment is in the meter, it is possible to control feeders in the future without instrument modification. The feeder adaptations for this type of control are inexpensive. Only a 3 phase motor and an across-the-line magnetic motor starter are needed. Three-phase motors and across-the-line motor starters are used for long life and low maintenance of the feeder motor. The comments with regard to inexpensive adaptation of the feeder do not apply to chlorinators, which require a device for conversion of the impulse duration signal to a vacuum signal that may run into hundreds of dollars. Other possible means of control for chlorinators will be discussed later in this paper.

Another type of open loop control for chemical feed utilizes pneumatic transmission. It is readily adaptable to all of the previously noted types of feeders. Fig 3 illustrates the relationship of flow to the pneumatic signal. It is observed that one follows the other exactly, with none of the inaccuracy present in the impulse duration system. This system requires relatively inexpensive instruments. Its total cost runs about the same as an impulse duration controller but usually it requires a rather expensive feeder adaptation in the form of an air motor which varies the feed rate in proportion to flow. In addition, it requires a 20 pound air supply. This type of control is readily applied to all types of feeders but most logically applied to the gravimetric type. It can be applied where there are rapidly changing flows.

A related type of control is based on vacuum transmission which utilizes a vacuum transmitter consisting of a mechanical flapper nozzle relationship device similar to that used in the pneumatic systems except that air is drawn through it rather than applied to it. The ejector in the chlorinator furnishes the vacuum

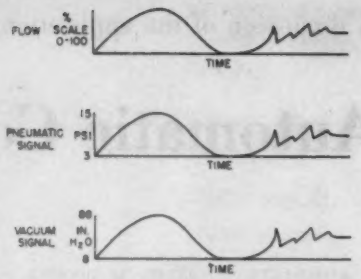

FIG 3 RELATIONSHIP OF FLOW to pneumatic and vacuum signals (open loop control)

and the vacuum controller constitutes a controlled leak in the vacuum system. Readily applied to most modern chlorinators, it requires an inexpensive instrument and an inexpensive chlorinator adaptation. It provides accurate control of the chlorinator in proportion to flow with neither compressed air nor electricity required. It is probably the best method of controlling chlorinators in proportion to flow rate in the smaller and medium size installations. The main advantage is that it continues to function as long as there is a water supply to furnish a vacuum to the ejector of the chlorinator.

Closed Loop Control

Closed loop control actually makes a measurement of the quantity of chemical being delivered and compares it against the desired quantity. Through this technique, precise control is possible. For practical purposes, it is limited to control of liquids and is typified by the control of liquid alum flow with an integral orifice differential pressure cell. Here, the liquid alum flow to the injector is regulated by a control valve which, in turn, is actuated by a recorder controller receiving a measurement signal from an integral orifice differential pressure cell transmitter. Better control than is possible with volumetric feeders and positive displacement pump is readily achieved. Normally no re-pumping of the chemical is required and the overall installation is simplified. Control of alum feed rate in proportion to plant influent is readily accomplished with this type of equipment, as illustrated by Fig 4. In this case, the control index of the alum flow controller is set by the plant influent rate. If the influent rate changes, the alum rate changes in proportion.

Table I

Errors for Dry, Liquid and Gaseous Feeder Pacing at 100% of Flow

	Impulse Duration % Pulse		Pneumatic 3-15 PSI		Vacuum 8-88 In. H_2O Vacuum	
	Maximum	Probable	Maximum	Probable	Maximum	Probable
Dry Feeder Volumetric	5.75%	5.05%	6.50%	5.12%		
Dry Feeder Gravimetric	1.75%	1.25%	2.50%	1.50%		
Metering Pump	2.75%	2.13%	3.50%	2.29%		
Chlorinator	5.75%*	4.18%*	5.50%	4.15%	7.00%**	6.07%**
Feedback Ratio Control (Liquids)			2.00%	1.41%		

Individual Accuracies

Impulse Duration	.75%	Dry Feeder (Vol.)	5%	Pneumatic Operators	1%
Pneumatic	.5%	Dry Feeder (Grav.)	1%	*Impulse Duration	
Vacuum	1.0%	Metering Pump	2%	Vacuum	
		Chlorinator	4%	Converters	1%
		**Chlorinator (Vacuum Control)	6%		
		Feedback Loops	1%		

Maximum Error

$$-E_1 + E_2 + E_3 + \ldots\ldots E_n$$

Probable Error

$$-\sqrt{E_1^2 + E_2^2 + E_3^2 + \ldots\ldots E_n^2}$$

Dosage is adjustable within the instrument by changing the ratio between the two flows. This type of control is applicable to alum, caustics, acids and, in general, all fluids normally utilized in water treatment practice.

It should not be overlooked that chemicals fed as liquids in many cases result in greater efficiencies than realized with the dry form of the same chemical. An example is alum. At the Salem and Beverly Mass., Water Supply Board filtration plant, an average reduction of 19 per cent in alum consumption, dry weight, has been realized by conversion from dry to liquid alum.

A comparison, Table 1, of the expected accuracies with various types of control reveals some interesting facts. For dry feeders and metering pumps, simple, inexpensive, impulse duration control is more precise than other types, providing the rates of flow change slowly. For chlorinators, the simple inexpensive vacuum transmitter is sufficiently accurate to handle most applications. Liquid feed control is most accurately accomplished by feed back ratio control. Except with rapidly changing flows, pneumatic control of dry feeders and metering pumps is least accurate. For normal water works installations, it can be concluded that impulse duration control is the logical selection for dry feeders, and metering pumps and vacuum control for chlorinators. Feedback ratio control is most accurate for solution feed with the additional advantages of recording and continuous monitoring of feeder operations. It is apparent that accurate feeder pacing does not necessarily require elaborate and expensive equipment.

Concentration Control

A second type of closed loop control is concentration control in which the actual concentration of a substance is measured and the dosage then corrected so as to maintain concentration at a constant level. This type is illustrated by pH control, residual chlorine control, fluoride control, etc. Except for pH control, it has not been widely adopted in water treatment practice to date but should be in the future.

A typical closed loop control pH system is shown in Fig 5. The pH electrode is located in the pipeline and transmits an electrical signal to a pH recorder controller which, in turn, furnishes a pneumatic signal to operate a pneumatic control valve and admit chemical for pH correction.

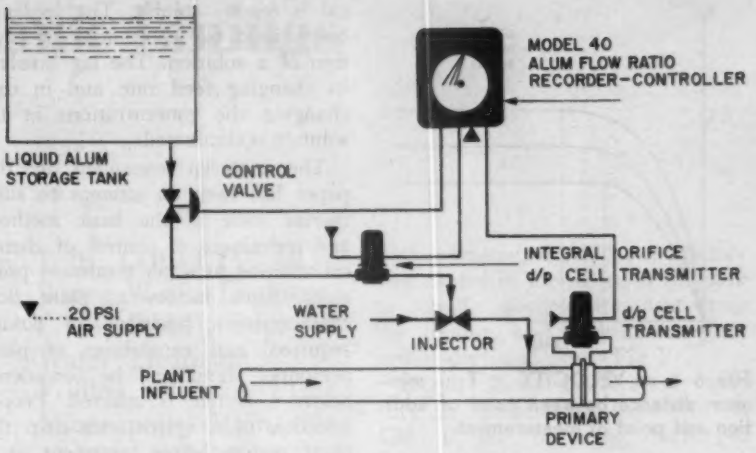

FIG 4 SCHEMATIC DIAGRAM of closed loop control of liquid feed

Some important cautions must be observed in the application of pH control. Although pH appears to be linear on the scale, it is actually a logarithmic value and the scale is a linear expression of a very nonlinear characteristic. A pH change of 1 unit represents a tenfold change in H^+ concentration.

Note that Fig 5 shows a dimension "L". Fig 6 establishes "L" as the minimum distance between the point of addition and the point of measurement. This minimum distance is best established by laboratory experiment in which units of acid or alkali to be used in the actual plant are added to the water and the pH observed over a period of time. For different dosages, a family of curves similar to Fig 6 might result. The value for "T" should be the longest time required to reach stability. Therefore, "L" becomes the velocity $\times$ time. If acids or alkalis are to be delivered to the water in liquid form, time is not normally a problem because the reaction rate is, for practical purposes, instantaneous. However, with materials such as dolimitic limestone, reaction times are very long. To control a system where the dimension "L" is less than the minimum distance is difficult, if not impossible. There will be wide differences between the laboratory pH measurements of the water, taken at a point farther downstream, and those shown on the recorder controller. Also the recorder controller will have a difficult time controlling because the reaction is in a transient state. Many pH installations in water treatment plants do not operate satisfactorily simply because this simple laboratory procedure was not performed before the installation was designed and placed in service. Another effect which must be considered in the application of pH recorder controllers is the buffering capacity of the water. The pH control point should be selected with accurate knowledge of the buffer points.

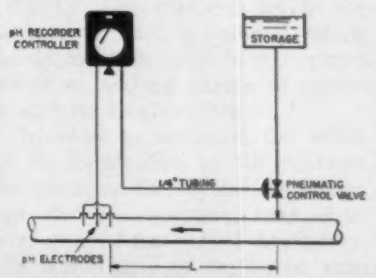

FIG 5 SCHEMATIC DIAGRAM of pH control system (closed loop control)

Although not always practical from a chemical handling standpoint, pH correction through the feeding of a liquid is preferred to dry chemical feed with the controller changing the rate of a dry feeder. Serious lags in the dry feeder many times make pH control with this type of feed almost impossible.

One means of avoiding or minimizing feeder delays on concentration control is to use a volumetric type of dry feeder, operating at a fixed rate higher than the maximum required and controlling feed with a control valve, Fig 7. Level con-

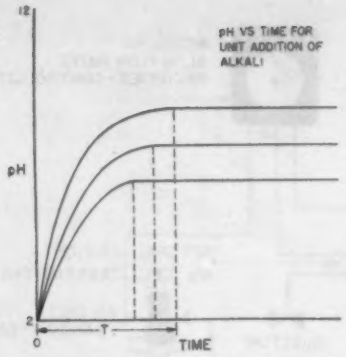

FIG 6 L = VELOCITY × T = minimum distance between point of addition and point of measurement

trols are necessary on the feeder to prevent flooding the solution tank. This results in an essentially liquid feed system providing the dry chemical is readily soluble. The feeder is being used for continuous preparation of a solution. The lag involved in changing feed rate and in turn changing the concentrations in the solution is eliminated.

The material contained in this paper has been an attempt to summarize some of the basic methods and techniques of control of chemical addition to water treatment processes. Such factors as plant flow characteristics, accuracy of dosage required, and capabilities of plant personnel should all be considered before a system is selected. Proper selection of a system can help the plant realize better treatment at a minimum expenditure for chemicals.

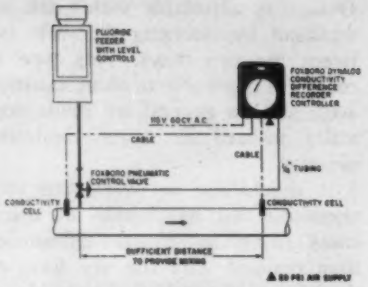

Fig 7 SCHEMATIC DIAGRAM Installation of Fluoride Concentration Recorder-Controller

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Liquid Alum Tank Linings

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■ DURING JANUARY 1957, the Minneapolis Water Department started investigating the advantages of liquid alum over dry alum. Inasmuch as there was a definite saving, as far as cost was concerned between the price of dry alum and liquid alum ($3.34 per ton on dry basis), and because there would also be a definite saving in labor costs, it was decided to make provisions for using liquid alum at each of the three plants: the Softening Plant, the Fridley Filtration Plant, and the Columbia Heights Filtration Plant.

The Columbia Heights Filtration Plant does not have any railroad siding. Therefore, all bulk chemicals have to be delivered to one of the other plants to be unloaded and then rehandled and hauled to the Columbia Heights Filtration Plant by truck. This involves extra expenses that would be eliminated if liquid alum were used. At the other plants, labor costs could be reduced and maintenance costs on the pneumatic conveyor equipment practically eliminated.

Because of the low pH (2-3) of a 50 per cent alum solution, any tank used for its storage must be lined with a non-corrosive material. The alum producers recommended lining the tanks for storage of liquid alum with sheet lead, the installed cost of which would come to approximately $5.00 per square foot.

It was difficult, and yet it seemed that to obtain any definite information on any other lining material, at this stage of our National technology there must be some type of coating available that would serve the purpose and still be much cheaper than lead. As a result, a research project was started to test linings under actual operating conditions.

Fig. 1. A CONCRETE TANK FLOOR deeply pitted from being used to dissolve dry alum in water.

Operating Conditions

First, a concrete tank, 14 in. x 17 in. x 17 in. inside dimensions, was constructed with the idea that it would act as a holding tank for liquid alum in which concrete brick, coated with various expermental linings, could be placed.

The sides of the experimental tank were left rough with numerous pits in order to simulate the three concrete tanks at the Columbia Heights Filtration Plant. These tanks were located in the basement of the plant and had been used years ago to dissolve dry alum in water, the resulting solution being added to the water as a coagulant instead of the dry alum itself.

As a result of heavy use of these concrete tanks for this purpose, the sides and floor were deeply pitted (Fig 1). This condition led to the attempt to find a material which would cover the tanks in their pitted condition, without having to mortar smooth the rough surface.

In order to accelerate the action of the liquid alum on the different materials and thereby demonstrate an extended life expectancy from whatever material that proved satisfactory, the temperature of the liquid alum solution was maintained at 150° F by means of a thermostatically controlled heating element. An agitator was located in the center of the tank to rapidly disperse the heat from the heating unit and continuously agitate the liquid alum (Fig. 2).

Liquid alum, as received, may vary in temperature from 100 to 120° F, but, on being discharged into the storage tank, cools rather rapidly either by radiation or by being diluted by liquid alum already present in the storage tank. It was decided that a lining that would hold up at a temperature of 150° F for a specific period would have an extended life at much lower average temperatures.

A number of companies that manufactured coatings they thought would withstand liquid alum at a temperature of 150° F submitted samples for testing. The Water Department furnished the concrete brick and most of the companies coated the bricks at their own plants. Whenever the Department coated the brick, they followed the manufacturers instructions implicity, though it was considered preferable that the manufac-

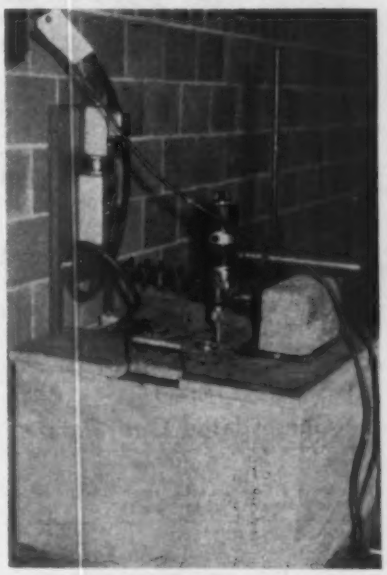

Fig. 2. AN AGITATOR located in the center of a tank to rapidly disperse the heat from the heating unit and agitate the liquid alum.

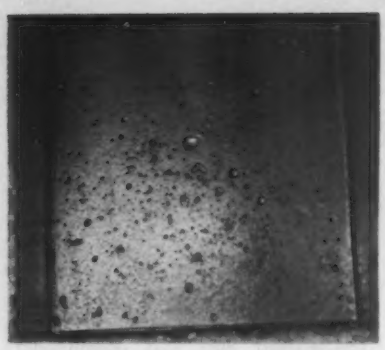

Fig. 3. CONCRETE EXPERIMENTAL tank coated with two coats of an epoxy resin.

turer do the coating to insure it was put on according to their specifications.

The concrete experimental tank was coated with two coats of an epoxy resin (Fig. 3). On December, 4, 1957 the coated bricks were placed in the tank with liquid alum.

The bricks and the tank were inspected every two weeks or oftener so those bricks whose lining failed could be removed before the liquid alum could attack them and weaken the solution. Indications of a break in the coating or a defective coating was indicated by bubbles in the liquid above the brick.

Tests were run on the liquid alum periodically to make sure its strength was maintained. As the water was evaporated from this solution, because of the high temperature, distilled water was added every twelve hours to keep the volume of liquid constant.

Many bricks were removed from the solution a few minutes after submergence, because of immediate failure of the coating. Others remained in the tank for varying times up to 18 months.

The tank lining failed after a period of five months. The inside of the tank was sandblasted and coated with four coats of chemically resistant white vinyl coating. This vinyl coating remained intact and was in excellent condition at the end of fifteen months, the extent of the experimentation.

As a result of the experimental work, it was decided to coat one tank at the Columbia Heights Plant with a paint called Glid-Iron.* This product had remained intact for four months and appeared in excellent condition. The material was ordered and the brick removed from the test tank. The following morning this brick had developed cracks at its edges.

This material apparently could not stand the changes in temperature from 150° to room temperature, and it was therefore decided not to use this material.

Instead, the vinyl coating that had been used to coat the experimental tank was chosen. This material had remained in excellent condition for a period of ten months, and it was felt that because of the cost of application it would be much cheaper in the long run to use this material than to use lead.

The vinyl coating could be sprayed on in coats of 1½ mils thickness per application. After sandblasting the walls and floor, the walls and floor of one tank (13 ft x 13 ft x 13 ft) were coated with five coats of this material to give a thickness of 7½ mils. Any pinholes remaining after the second coat were filled with a mixture of vinyl and whiting. The drying time between coats was two hours. The walls were coated first and then a suspended scaffold was used to apply the coatings to the floor. Because of the extreme roughness of the surfaces, it was difficult to do a good job of covering all the surfaces.

In May of 1959 the first liquid alum was added to this tank. In August the tank was emptied and inspected. At the bottom of one wall on the floor a three foot by six inch strip of the vinyl had come loose. There was also one spot on the wall, the size of a silver dollar, where the vinyl had been removed. On investigation the reason was found that the floor of the tank was porous and thin because of the years it had been used to dissolve dry alum in water, and groundwater had seeped up through the floor at this one spot.

A six inch reinforced concrete floor was then poured on top of the old floor and, after drying, it was coated with five coats of vinyl. The spot on the wall was covered and the tank put back into service.

It was decided that a much better job could be done on the second tank if after sandblasting a concrete floor was poured and the walls of the tank were mortared smooth. This was done and the second tank was coated with five coats of vinyl the same as the first. This tank was put into operation in August of 1959.

After a period of one year of service, both tanks are still in excellent condition with no indication of any failure of the coating.

The concrete tank at the Fridley Filtration Plant is located on the second floor of the Plant. This tank is constructed in the shape of a cube with a hopper bottom. It had been used as an activated carbon storage tank. The capacity and surface area are given in Table 1.

This tank was coated with a product called Duro-crete*, an epoxy resin with a silica binder. A binder, hardener and aggregate were mixed and troweled onto the surface of the tank. The resulting thickness of the coat was from ¼ to ½ inch. This material is difficult to apply to a wall surface and after it is mixed has to be applied within a 60 minute period or it gets too hard. It must be applied in small quantities and worked into the previously troweled surface.

The labor cost per square foot for the application of this product was much greater than the cost of the

*Product of Glidden Paint Company, Minneapolis, Minn.

*Product of Electro Chemical Engineering and Manufacturing Company, Emmons, Pa.

Table 1

Consolidated Cost Data

Location of Tank	Lining Material	Tank Capacity cu. ft.	Tank area not including roof sq. ft.	Total Cost	Cost per sq. ft.
Columbia Heights	Vinyl	2197	945	$1461.00	$1.55
Fridley Filter Plant	Duro-crete	1930	1075	2702.00	2.51
Softening Plant	Edgco #3	6950	2031	3081.00	1.51*

*Cost of installing 10 inch floor not included ($2400.00)

Table 2

Softening Plant

1. Cost of Materials	
(a) 185 gallons Edgco Neoprene Brush Coat #3 with accelerator at $10.50 gal. in 50 gallon drums or $11.00 per gal. in 5 gallon pails	$1960.00
2. Labor Cost 344 Man hours at $3.26	1121.44
Total Cost	$3081.44

Table 3

Columbia Heights Filtration Plant

1. Cost of Materials	
30 Bags Sand at .70	$ 21.00
10 Bags Cement at 1.17	11.70
30 Gallons Vonyl Paint at 4.95	148.50
30 Gallons Thinner at 1.34	40.20
Installation of 6 inch floor	310.00
	$ 531.40
2. Labor Cost	
Sandblasting, 168 man hours at 2.60	$ 436.80
Mortaring Walls, 48 man hours at 3.75	180.00
Vinyl applications, 96 man hours at 3.26	312.06
	$ 929.76
Total	$1461.16

other products (Table 4). Although the overall cost per square foot for this product was higher than the other products, it will hold up better and give less trouble than the other products. This tank was placed in service on October 21, 1959.

A large overhead concrete tank at the Softening Plant was lined with seven coats of Edgco Neoprene Brush Coat #3.* This tank had previously been used for storage of bulk lime. Before using it for storage of liquid alum, a ten inch reinforced concrete floor had to be poured in order to decrease the angle of slope near the walls. This minimized cracking at the wall-floor joint. This product can be applied by brush, roller or spray. On this job, rollers were used and the coating applied from a scaffold suspended from the ceiling. This tank was 52 feet long and had two, 2 ft x 3 ft, openings, one at each end of the tank.

The Edgco has a volatile solvent that is toxic; therefore care has to be exercised in its use to make sure proper ventilation is available for the tank. This was one of the most difficult points to provide in the application of this product. Two air hoses were provided for the tank and a suction fan was installed at one of the openings. The painters found it difficult to remain in the tank for extended periods of time.

One coat of neoprene was applied each day. Each coat had to be applied to the previous coat while the coat was still tacky. If the coat sets too hard over night the surface then has to be sprayed with the solvent before the next coat is applied.

Inspection of the surface after the final coat had dried and the scaffold removed from the tank showed a number of small spots along the bottom of the wall not covered satisfactorily. It was difficult to apply these coats from a suspended scaffold and to cover thoroughly the area below the scaffold, especially since the walls had numerous small depressions throughout. The small openings that had not been covered properly were filled with putty.

Liquid alum was placed in this tank on February 2, 1960. On inspection of this tank after three months of service there was one spot that had to be filled with putty. All

*Product of K. A. Steel Chemicals Inc., Chicago, Ill.

Table 4

Fridley Filtration Plant

1. Cost of materials	
54 Cartons Duro-Crete at 21.75	$1174.58
8 Gallons Nitro-Dur 100 Thinner at 8.50	68.00
	$1242.50
2. Labor Cost	
Application, 320 man hours at 3.26	$1043.20
Application, 160 man hours at 2.60	416.00
	$1459.20
Total	$2701.70

of these coatings are in excellent shape at the present time. The two tanks at Columbia Heights Filtration Plant and the tank at the Fridley Filtration Plant have been in service for one year. The tank at the Softening Plant has been in service over eight months.

It is too early to predict the life of these coatings but, from the standpoint of cost, the vinyl coating looks the most promising. If only the cost of material and the application of the coating is considered the vinyl cost is $0.53 per sq ft. The additional cost of $1.02, as shown by Table 1, includes sandblasting, a reinforced concrete floor and covering the walls with a layer of mortar to make them smooth. To give the best results for the application of vinyl, it is recommended the tank walls and floor be smooth. Under these conditions the cost is reasonable and the coating can be expected to last for years.

Investigation shows corrosion and red water stop where . . .

Calcite Coating Protects Water Pipes

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EDITOR'S NOTE: The results of distribution system corrosion are well known. Theories explaining the cause, together with practical means of controlling corrosion have been advanced from time to time, yet water quality continues to deteriorate in the distribution system. Dr. McCauley describes here a practical means of insulating pipe from attack through careful control of calcium carbonate and polyphosphate content. Field trials are needed to define optimum concentrations required during coating formation and levels which should be carried throughout the system to retain and improve the protection.

■ AFTER 20 YEARS or more of service, unlined cast iron and steel pipes experience increased friction due to internal pipe corrosion. In time, the reduction in carrying capacity may be 60 percent or more.[1] To avoid these large economic losses many waterworks managements now require that new metal pipes be cement or coal tar lined.

Unfortunately, a large part of the capital investment of many distribu- with mechanical equipment.[2] For iron and steel. When friction losses become excessive, the corroded pipe tion systems is in older, unlined cast must be replaced or cleaned in place cleaning, access openings are cut at two sections of a line several hundred feet apart. Hydraulically or mechanically driven equipment is then used to clean out the incrustations which restrict pipe flow and cause excessive friction losses due to roughness of the pipe walls.

Cleaning usually restores most of the pipe capacity for a time. The removal of corrosion products during cleaning almost invariably accelerates the corrosion of newly exposed bare metal and the restored capacity is often lost, sometimes in a few months or less. For this reason, many water utilities have discontinued cleaning of mains unless the pipes can be simultaneously cement or bituminous lined.[3]

Rehabilitation of badly corroded iron and steel mains is usually accomplished by cleaning and cement lining. Cleaning does not represent a large capital outlay; cement lining is far more expensive. One reason for the large cost of cement lining is the labor and time required. During the lining process temporary lines are usually laid to provide customer service. As a result, the cement lining of several thousand feet or more of pipe becomes a sizeable municipal project.

The cost of cleaning and cement lining of water lines is often 40 to 75 percent of the outlay for new mains.[4,5] In congested downtown business districts, cleaning followed by cement or bituminous lining may be the only economic means for restoring adequate water service. For outlying areas, the price differential between lining and pipe replacement may not be great. Regardless, the rehabilitation or replacement of large sections of distribution systems becomes very expensive and many communities with a serious need for these improvements have found it necessary to defer them for indefinite periods of time.

Because corrosion proceeds continuously in most distribution systems, increased friction losses are usually

preceded and accompanied by the plague of "red water" which may at times render a domestic supply unusable for general household purposes. Epidemics of rusty water are common to many water utilities during periods of high demand for lawn irrigation, following the use of fire hydrants or other disturbances in distribution mains.

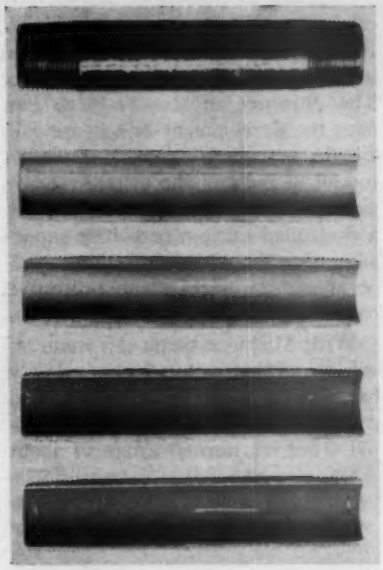
Anti-Corrosion Water Treatment

The previous discussion points out the value of anti-corrosion water treatment processes which permit corroded water mains to be cleaned without the attendant expense of cement lining. Processes which develop protective anticorrosion coatings on the pipe walls throughout a water system are equally useful. An ideal treatment process which accomplishes both of the above ends should satisfy these requirements: (1) the treatment should be a normal and simple part of conventional water treatment, (2) substances added to the water and their reaction products should be non-toxic, (3) the treatment should cause no change in the palatability or industrial quality of the water, (4) no incrustations should be developed which interfere with water meters or with heat transfer in hot water heaters, (5) the treatment should be relatively inexpensive, (6) corrosion of newly bared metal after cleaning of distribution mains should be arrested and (7) throughout the system there should be an alleviation of corrosive conditions which cause "red water" and in time lead to serious impairment of carrying capacity.

Three treatment processes for providing anti-corrosion protection of iron pipes are now used in practice: (1) calcium carbonate ($CaCO_3$) or egg shell depositions, (2) the addition of between 1 and 4 mg/liter of sodium polyphosphate and (3) the addition of 12 to 16 mg/liter or less of sodium silicate. Each of these protective practices has had wide use, but none has proved uniformly successful for permanently arresting water main corrosion.

Research Program

Because of the serious need for better and more reliable anti-corrosion treatment procedures the author has cations.[6,7,8] To date, all work has undertaken research which has previously been reported in several publi-



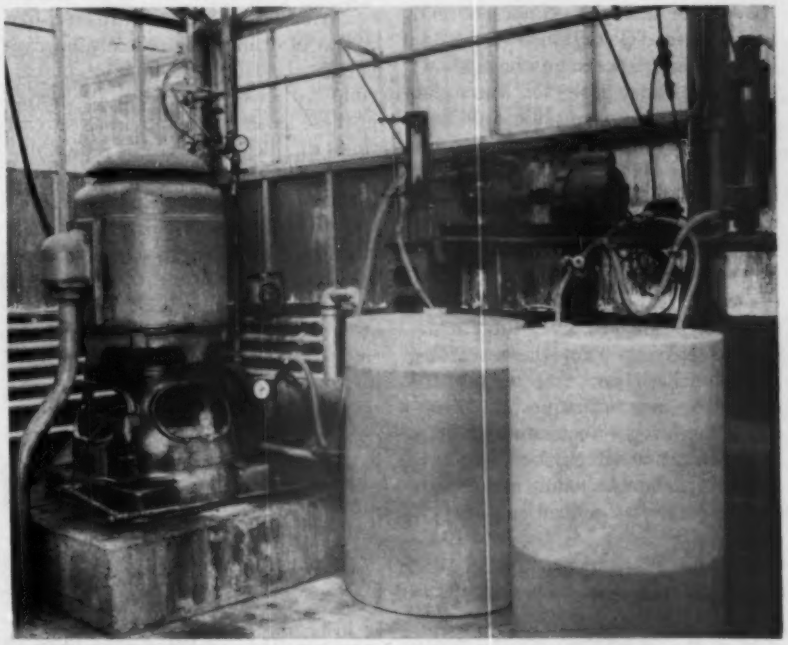
IRON PIPE NIPPLES cut to show interior walls. Pair in center show bare metal surface after sandblasting, while pair at bottom were sandblasted and coated. Translucent calcite coating was formed in two hours.

been with protective calcium carbonate (calcite) coatings. A better and more complete understanding of several important factors which govern these depositions has resulted. In addition, a simple, inexpensive and practical 2 hour field procedure for laying down hard protective calcite coatings has been developed.

Results from Preliminary Investigations

Initial experiments of this work were designed to establish test conditions which were similar to those which might exist in newly cleaned water distribution mains or in systems which had experienced long histories of corrosion. Experiments with both tap and synthetic waters soon showed that calcium carbonate scales were not easily laid down in water distribution systems. It was also discovered that newly bared metal (represented by sandblasted cast iron specimens) corroded more rapidly than had been anticipated. In "unsaturated" Michigan State well water, containing about 6 mg/liter of dissolved oxygen, the specimens rusted badly within 12 hours under static (zero flow) conditions. With a flow velocity of 0.5 feet per second the rusting was not so apparent. Checks on weight loss of metal showed that the absence of heavy rust deposits under conditions of the above and slightly higher flow rates was primarily due to a continued removal of corrosion products. That is, corrosion of the initial bare metal was not greatly affected by velocity at relatively low rates of flow.

A series of studies was next initiated using waters with $CaCO_3$ concentrations above the saturation level. With various $CaCO_3$ supersatura-



WELL HOUSE during field experiments on Michigan State University campus. Shown are 350 gpm well, chemical solution tanks, pumps and rotameters.

tions, mixed coatings of iron oxide, iron carbonate and calcium carbonate did result. Flow velocities of 2 feet per second or higher were required in all cases to develop these iron-calcite deposits. Soft iron oxide which provided no apparent anti-corrosion protection developed on the metal during all static tests.

Limitations on the Development of Egg Shell Coatings

As a result of these experiences it has been concluded that the conventional adjustment of a water to a positive saturation or Langelier index[9] is not a procedure which in itself assures that corrosion will be arrested. This author is now of the belief that protective calcium carbonate coating cannot develop on corroding iron until the very high initial corrosion rate is reduced. Moreover, the presence of flocculent iron oxide or other soft depositions inhibits the development of protective coatings, even in the presence of calcium carbonate supersaturations. For static or low flow conditions it appears that satisfactory protective deposits will not be developed, regardless of the $CaCO_3$ supersaturation. With flow velocities of 2 feet per second or higher a relatively hard, but porous protective coating may result.

Most water distribution systems experience static or very low flow conditions during much of the midnight to six o'clock period of the day. While these experiments have shown that the soft deposits of iron oxide which develop under static conditions inhibit calcite coatings, a positive saturation index may eventually result in protective iron-calcite deposits if high velocities are experienced at regular intervals. For dead ends and low flows it seems doubtful that conventional levels of $CaCO_3$ supersaturation will be helpful, even after many months or years. For these reasons, attention has been directed toward developing new techniques for formulating the levels of calcium carbonate supersaturation which should be carried in distribution mains and for arresting corrosion in dead end areas.

Work With Large Calcium Carbonate Excesses

As a step toward developing improved techniques some eighty experiments have been made with large calcium carbonate supersaturations. Flow velocities for these experiments have been 2 feet per second or higher. The objective of this research has been the development of a dense calcite deposit which is capable of arresting all or most of the metallic corrosion. With this type of base deposit a controlled calcium carbonate supersaturation should result in the growth of an almost pure calcite protective coating.

With Michigan State tap water, it was found that within 2 hours a very hard, dense coating could be laid down on bare metal by adjusting the pH from it's normal range of about 7.2 to a value of 9.0 or higher. The very large calcium carbonate excess and high flow velocity stifled rusting and permitted development of very useful anti-corrosion coatings.

SECTION OF 6 IN. CAST IRON PIPE, two feet long, used in field coating experiment.

During these experiments, the piping and tubes of the experimental equipment were filled with sand-like grains of orange colored calcium carbonate. Usually, the amount of calcium carbonate lost from the water in these loose precipitates was several times that deposited on the pipe walls. It was therefore concluded that some further control of the coating process was necessary for any practical development of protective depositions. For this control, experimental work was then begun by the addition of various concentrations of a polyphosphate commonly used by many water utilities.

Control of Calcite Depositions with Polyphosphate

A laboratory procedure has now been developed for Michigan State University tap water which provides positive assurance for the development of excellent protective coatings. In brief, the coating process requires the addition of about 0.5 mg/liter of phosphate (as PO_4) and a calcium carbonate excess, expressed in terms of a "Driving Force Index", of about 100. Computation of the "Driving Force Index" or DFI is straightforward and poses no problem other than becoming acquainted with the mechanics involved in the various steps of its determination.

This level of calcium carbonate excess and metaphosphate concentration, together with a flow velocity of 4 to 6 feet per second, has invariably resulted in hard, translucent protective calcite coatings from Michigan State tap water. Storage of coated samples in oxygen saturated water for long periods of time has showed the coating to have unusual anti-corrosion qualities. If stored in a water which is saturated with calcium carbonate the coating has improved with time.

The coating which is developed by these procedures is quite different from that associated with so-called egg shell deposits. Viewed under the microscope at 100X magnification the deposit is observed to be a translucent, glass-like material. For sandblasted cast iron samples the treated sample is identical in color to the metal previous to treatment. Close observation through the microscope reveals that the initial, untarnished metal shows quite clearly through the calcite coating.

In one test, coated and uncoated specimens were stored for 12 hours in beakers and then compared. The water containing the coated specimens showed no noticeable change. For the untreated specimens, the water was deep red and flocculent iron oxide covered both the specimens and the bottoms of the beakers.

Figure 1 shows two iron nipples which have been cut to show the interior walls. The sections on the left are sandblasted bare metal, the two right hand sections are sandblasted nipples which have been coated by the 2-hour process. The translucent nature of the calcite coating is apparent in this photograph.

Field Experiments

Theoretical computations indicate that this same Driving Force Index, metaphosphate concentration and velocity should develop equally satisfactory coatings on pipes of any diameter. To test the validity of this deduction, a 1200 foot section of 6 inch

cast iron pipe which leads from a campus well to a concrete reservoir was selected for field testing. The well produced a water of the chemical quality of Table 1. Capacity of this pump was 350 gallons per minute, with a resulting pipe velocity of 4 feet per second. The well house piping permitted metaphosphate to be fed at the discharge point from the pump housing into the distribution main. The water was well mixed with the metaphosphate as it travelled through a check valve, elbow and propeller meter.

Sodium hydroxide was fed at the outlet point from the well house to provide the pH adjustment for the required DFI level. Figure 2 is a view of the experimental equipment installed in the well house.

The 2 foot section of sandblasted cast iron pipe, shown in Figures 3 and 4, was dropped in place on the end of the 1200 foot main when the metaphosphate level and DFI were found by chemical analysis to have reached the proper level. Analysis of calcium, alkalinity and pH were made each 10 minutes during the run. Because of the 30 minute refluxing required for metaphosphate determinations only four samples could be checked for phosphate during each experiment.

After several tests to check equipment and to establish the correct chemical feed levels a carefully controlled field experiment was made. DFI and metaphosphate levels for the experiment were at the proper levels of 100 and 0.5 mg/liter respectively. The 2 foot cast iron pipe had been sandblasted inside of each end, then used during several of the initial test runs and finally washed with strong acid. As a result, the metal of the pipe was covered with a brown rust stain but was otherwise clean when the experiment began.

Throughout the experiment, a continued drop of 8 to 12 mg/liter of calcium (as $CaCO_3$) was noted in the 1200 foot main. This drop provided good assurance that calcium carbonate was being continuously deposited. After 2 hours, the pipe section was removed and found to have developed a coating on both sandblasted ends and on a coal tar enamel in the center section. The coating was quite similar to that observed in laboratory experiments when using ¾ inch black iron pipe nipples.

The field-coated pipe has shown excellent anti-corrosion qualities which will undoubtedly improve with time in a water carrying the proper level of calcium carbonate supersaturation. Figure 5 shows the reservoir discharge line in operation with pipe section installed. Additional tests of these field procedures were not carried out during winter months because of a number of local problems which make further work along this line impractical during cold weather. Further testing of the process will be made early in 1960, though there appears no valid reason to doubt that future experiments will be less successful than the initial test. Field tests are also being considered for a number of water systems throughout the nation.

Results

The laboratory and field experiments just described indicate that a useful inexpensive field procedure has been developed for combating water main corrosion. In many ways, the process appears to satisfy many of the criteria previously mentioned for the ideal anti-corrosion water treatment process. However, it is important at this time to view these developments in the light of the present level of field and laboratory experience:

1. The one successful *field* coating of a two foot section of 6-inch pipe was with a water typical of many well sources in southern Michigan. There is every reason to believe that other waters will perform equally well under future testing. The greatest need now is for broad field testing with waters which are low in initial calcium and alkalinity. The criteria which have been mentioned for field treatments are by no means fixed at this time, and must wait on a number of tests with different type waters before being firmly established.

2. Laboratory and field procedures are simple and have been successfully carried out by undergraduate Civil Engineering students with limited training in chemistry. These young men have worked on the project for some time and have become quite familiar with the required techniques. Certain very strict controls are necessary and without these controls the process fails. A reasonably high level of technical competence appears essential to success with the methods described here.

SANDBLASTED interior of 6" cast iron pipe section before field coating experiment.

Field and Laboratory Procedures for Coating Development

For both small scale laboratory testing and full scale field experimentation the technique for coating development has been much the same. The basic principle is the development of a large calcium carbonate excess which is controlled and prevented from precipitating by the addition of about 0.50 mg/liter of polyphosphate. When this chemical adjustment of the water is accompanied by a 4 to 6 foot per second velocity the deposition of a hard, dense coating takes place within 2 hours.

In order to more accurately define the calcium carbonate excess which is required in this work the author has used both the Momentary Excess values of Dye (10), termed ME, and the value designated as Driving Force Index or DFI. The ME value is a statement of the supersaturation of the water and often represents the tendency of the calcium carbonate to be precipitated to the equilibrium level. However, in some waters the concentrations of calcium and carbonate are unequal. For instance, one test water contained 40 mg/liter of calcium and 200 mg/liter of carbonate (expressing both values as calcium carbonate). In this case, the precipitating tendency of the calcium carbonate was best expressed as a Driving Force Index or DFI. The DFI for a given water is the ratio of (the product of the calcium as $CaCo_3$ and the carbonate as $CaCo_3$) to (the product of the calcium and carbonate

at equilibrium). The ME is expressed as mg/liter, while the DFI is a dimensionless ratio. An example of the computations involved in these determinations is given in the appendix.

When a water is high in alkalinity and contains 50 mg/liter or more of calcium (as $CaCo_3$) the ME and DFI may be adjusted to the proper level by the addition of lime, caustic soda or soda ash. Lime is the cheaper and more effective treatment, but increases the calcium hardness. If calcium is low, the concentration may be increased by adding either lime or calcium chloride. Again, lime is preferable. If there is a deficiency in carbonate alkalinity it is necessary to add both lime or calcium chloride plus soda ash.

added far enough upstream from the point of pH adjustment to permit complete mixing. If soda ash, lime, or caustic soda is fed for pH adjustment previous to a complete mixing of the polyphosphate with the pipe flow, a satisfactory coating will not result.

Both the DFI and the polyphosphate concentration appear to be critical. Polyphosphate should be within the range of 0.40 to 0.60 mg/liter, with a value of 0.50 mg/liter appearing optimum. DFI should be about 100. For Michigan State studies, the ME has been 85 mg/liter for best results. A 4 to 6 foot per second pipe velocity seems most desirable, although satisfactory coatings have been developed in the laboratory at lower flow rates.

CAST IRON PIPE SECTION in place for testing at discharge point into reservoir. Coating developed in two hours and showed excellent anti-corrosion qualities.

For developing a 2-hour coating in the field the addition of soda ash and (if necessary) calcium chloride seems best. These chemicals are commonly available at low cost, can be added to water distribution systems without danger and because of their large solubilities are easily fed into the mains. Cost of chemicals for coating 1000 or more feet of pipe is $5.00-$10.00. It is best to use a constant, rather than pulsating type of feed. In experiments at Michigan State University both centrifugal and screw-type pumps have been very satisfactory.

It is essential that both the polyphosphate and calcium chloride be

The process is easily controlled in the field by maintaining a calcium drop of 8 to 10 mg/liter per 1000 feet of pipe. The conventional EDTA method for calcium determination makes this method of control quite simple. It is also well to check the drop in total hardness and alkalinity, for if these determinations are in terms of calcium carbonate, the drop should be identical to that for the calcium.

Continuous checking of pH throughout the 2 hour period is necessary. After 40 minutes to an hour a marked drop in pH level is often noted. This drop is a warning that the rate of calcium loss in the line may have become excessive and the pH and alkalinity should be reduced to the level which maintains the proper rate of calcium loss. Because it may be necessary to change pH and alkalinity levels during a run, the process control is best accomplished by a continued monitoring of the calcium level.

Saturation Excesses for Potable Waters

With ¾ inch pipe nipples it has been observed that coatings deposited during 2 hour treatments are dissolved rather quickly if the pipe is filled with a water which is undersaturated with calcium carbonate. The level of supersaturation which should be routinely maintained in the system cannot now be recommended except on the basis of present practice. Several years of experience in the Lansing, Michigan, water treatment plant, which lime-softens a water similar to Michigan State tap, has resulted in the use of a Momentary Excess or ME of 12 to 14 mg/liter of calcium carbonate.[10] The supersaturation is controlled by a polyphosphate level of 0.25 mg/liter for water when leaving the plant. Riehl has suggested a slightly lower $CaCo_3$ excess with 0.50 mg/liter of polyphosphate.[11] It appears that large calcium carbonate supersaturations can be maintained in the presence of polyphosphate without damage to water meters, house plumbing or hot water heaters. Cost of this treatment varies from $1.00 to $10.00 per million gallons.

There is still a definite need for more information with respect to the optimum $CaCo_3$ excess which should be carried for most effectively overcoming "red water" and other corrosion problems. With the Lansing lime-softened water, rust problems have largely disappeared, even in sections of the system which had previously been problem areas. To test the effectiveness of the Lansing water on newly cleaned iron, two sandblasted ¾ inch black iron nipples were inserted in a feed line of the plant which alternated between zero flow and a velocity of about 6 feet per second. After 6 months service, the nipples had developed a hard, mixed coating of calcium carbonate and iron oxide between 1/8 and 1/16 inch in thickness. While the coatings showed relatively good anti-corrosion qualities,

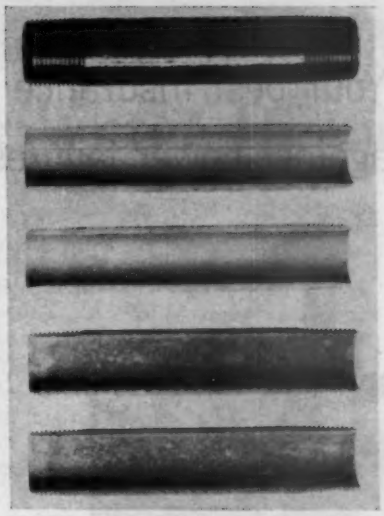
incipient tuberculation was quite evident. Figure 6 shows sections of these sandblasted nipples before and after the 6-month period.

Conclusions

On the basis of a large number of laboratory and one field study with a 6 inch cast iron pipe it has been demonstrated that a satisfactory base cast of calcium carbonate can be developed on iron pipe in 2 hours. By maintaining a phosphate level of 0.25-0.50 mg/liter and Momentary Excess of 12-15 mg/liter of calcium carbonate in the distribution system this coating should improve with time.

Further field testing with a number of waters is essential to further define the optimum levels of polyphosphate, Driving Force Index DFI, and Momentary Excess ME which should be maintained during the 2 hour period. More information is also desirable on the ME and DFI which should be carried in distribution systems to retain and improve the coatings.

For cast iron pipes which have not yet reached a level of deterioration which requires cleaning it seems quite probable that an iron-calcite coating



THREE-QUARTER IN. NIPPLES USED IN LANSING, Michigan. Lime-softened water experiment—center pair shows sand blasted surface—pair at bottom shows results after six months exposure.

can be developed and maintained by carrying a Momentary calcium carbonate Excess of 12-14 mg/liter. Control of this supersaturation requires between ¼ and ½ mg/liter of polyphosphate. Coatings of this type developed from Lansing, Michigan tap water have shown a capacity to reduce corrosion rates but have not arrested tuberculation.

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A Manometric Method for Measuring Corrosion in a Water Distribution System*

by WARREN H. OLDAKER
Sanitary Biologist
Mass. Dept. of Public Health, Boston, Mass.

■ ONE OF THE major perennial problems facing the water superintendent is the degree of corrosion present in his distribution system. If a consumer complaint is registered, which may involve corrosion, all too often there is too little actually known of the real conditions and the justice of the complaint.

Occasionally large sections of pipe are replaced on suspicion of corroded conditions, without any real knowledge of the necessity of replacement. The major reason for this lack of data is, I believe, the complicated and time-consuming method of dissolved oxygen sampling for which the average municipality has neither the personnel nor the laboratory facilities.

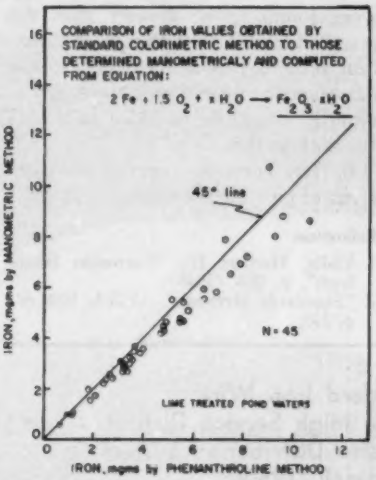
COMPARISON OF IRON VALUES OBTAINED BY STANDARD COLORIMETRIC METHOD TO THOSE DETERMINED MANOMETRICALY AND COMPUTED FROM EQUATION:
2 Fe + 1.5 O2 + x H2O → Fe2O3 xH2O
45° line
N = 45
LIME TREATED POND WATERS
IRON, mgms by MANOMETRIC METHOD
IRON, mgms by PHENANTHROLINE METHOD

FIGURE 1

In addition, D O sampling is cumbersome, in the field or in the laboratory. If a procedure could be offered giving equal information about corrosion which was simpler both in the field and in the laboratory, it could be of very significant assistance in the maintenance of distribution systems. This assistance could take the form of examination of whole sections, followed by surveys of smaller areas within the sections, if corrosion was indicated. With this procedure, it might well be possible for our district engineers to assist towns within their areas of responsibility by arranging and assisting in annual surveys.

At the beginning of this study of corrosion in the town distribution system, areas with either known or suspected corrosion were selected, and plotted upon a map. Sampling points were then chosen which contained the greatest number of corrosion areas in a section of reasonable size and accessibility.

Of course many factors, known and unknown, enter into the formation of areas, known or not, of corrosion. In this study, pipe bends, dead ends, pipe sizes and changes in size, elevation, distance from the source and the point of lime addition, location of water tanks, and accessibility for sampling were the main factors considered.

Field Sampling

Water samples were collected in BOD bottles from taps located in houses, barns, service stations, restaurants, and public buildings. Hydrant samples were not taken because of possible high background iron values. Five gallon samples were taken also from the raw source before and after lime addition.

Winkler-dissolved oxygen and temperature measurements were completed in the field. The more elaborate tests were completed in the laboratory.

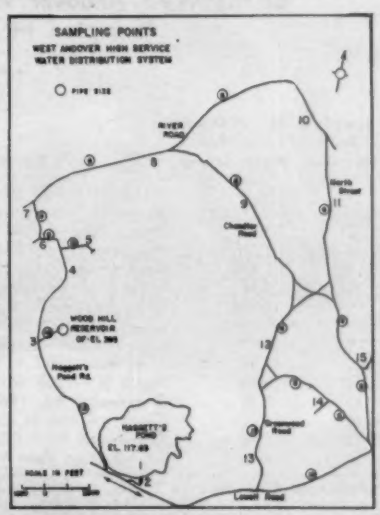

FIGURE 2

Laboratory

After portions of the samples had been removed for background chemical analysis, the remainders were pipetted into Warburg flasks. 25-cm lengths of reagent grade Baker iron wire No. 36 were coiled and a single coil was placed into each flask. Oxygen uptake values were obtained throughout the run of 10 days' duration.

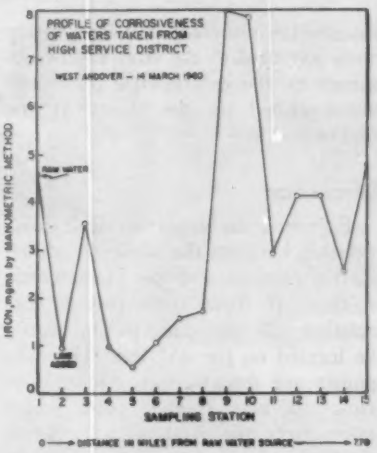
PROFILE OF CORROSIVENESS OF WATERS TAKEN FROM HIGH SERVICE DISTRICT
WEST ANDOVER – 14 MARCH 1960
RAW WATER
LIME ADDED
IRON, mgms by MANOMETRIC METHOD
SAMPLING STATION
DISTANCE IN MILES FROM RAW WATER SOURCE

Figure 3

At the end of the ten day time period, the water was removed from the flask and tested for total iron by the Phenanthroline method[1].

The observed oxygen uptake values were substituted in the equation:

$2Fe + 1.5\ O_2 + xH_2O = Fe_2O_3 \cdot xH_2O$

and the amount of Fe computed stoichiometrically. Comparison of the

* Reprinted with permission from the Fall, 1960 issue of "Sanitalk" a publication of the Mass. Dept. of Public Health, Division of Sanitary Engineering.

Table 1
Chemical Analysis of Waters
Taken from the High Service District of the
West Andover Water Distribution System
(Sampled 14 March, 1960)

Location	Tot-Iron mg/l	Tot-Sol mg/l	Hardness—mg/l Total	Calcium	Mag-nesium	Phenol-Alk mg/l	Tot-Alk mg/l	pH	D.O* mg/l
Haggetts Pond	.044	74	22	5.6	1.94	0	18	6.85	13.0
Haggetts Pumping Station	.051	84	50	13.6	3.88	3	35	8.75	9.45
Base of Wood Hill	.057	94	46	13.6	2.91	3	35	8.75	9.30
Haggetts Pond Rd.— 100' fr. High Pl.	.094	86	46	14.4	2.42	3	37	8.80	3.60
Pleasant St.—Dead End	.425	76	44	14.4	1.94	5	38	9.05	4.10
High Plain Rd.—Dead End	.209	84	48	14.4	2.91	4	37	8.92	7.30
River Rd.— 1000' fr. Boutwell	.548	84	48	14.4	2.91	2	38	9.00	7.90
River Rd.— 1000' fr. Chandler	.620	56	50	15.2	2.91	5	39	9.10	1.90
Chandler Road	.245	82	46	15.2	1.94	3	36	8.80	7.30
River Rd.—1000' fr. North	.562	86	48	14.4	2.91	5	39	9.05	4.40
North St.—1500 fr. Webster	.317	78	48	14.4	2.91	4	40	9.00	5.70
Greenwood Road	.480	92	48	13.6	3.40	3	36	8.85	8.20
Corner Beacon & Chandler Rd.	.570	114	48	14.4	2.91	4	38	8.90	5.50
Greenwood Rd.— 1500' fr. Lowell Rd.	.057	108	52	15.2	3.40	4	36	9.00	9.00
Corner High Plain Rd. & Rolling Ridge Rd.	.063	108	50	15.2	2.91	4	38	8.90	8.70

* As taken in the field (temp. range = 1.9 deg. C).

manometrically computed iron values were matched to the iron values obtained by the colorimetric procedure accomplished on the water at the end of the run.

Discussion

Figure 1 indicates a close relationship between the standard colorimetric method and the manometric method. If there were perfect correlation, all the data points would be located on the 45° line. The data points are drawn from 45 separate runs on lime treated pond water taken from the Andover and North Andover water systems.

Figure 2 represents the high service district in West Andover. Although the town system includes wellwaters, the high service district receives water only from the pond supply and for most purposes is in a closed loop making it ideal for a survey of this type. From the pumping station to the end of the loop, the distance is approximately 8.4 miles.

Table 1 is a summary of the chemical analysis of the water samples before testing in the Warburg apparatus.

Table 2 summarizes the corrosive effect of the various waters upon a sample of iron placed into the water. If the water is corrosive, the iron content will increase with time. The iron content is measured by the manometric and colorimetric method.

Figure 3 depicts the corrosiveness of the water in relation to the amount of standard iron wire attacked. Discounting stations 3, 9, and 10, the trend is gradually increasing. Simply, the greater the distance from the point of lime addition, the more the water tends towards the corrosive state of the raw, untreated water. A graph of this nature then should cause a review of the lime treatment control as well as spotlighting any obvious corrosion points as indicated at stations 3, 9 and 10.

Conclusions

1. The manometric procedure is simple to perform in the laboratory and results agree closely with the standard colorimetric procedure.

2. The manometric procedure is not subject to interferences as phosphates, fluorides, color, turbidity, chlorine or other oxidizing agents which may commonly occur in public drinking waters do affect the standard colorimetric methods.

3. Field sampling and laboratory procedures can be performed by one trained man in a reasonably short length of time.

4. The manometric corrosion testing method tests the corrosiveness of the water on a coil of reagent grade iron wire.

5. Iron values in the town water were found to be greater than the accepted standard. Although information such as this is incidental to the manometric testing procedure, it ordinarily would be included in a survey such as this.

6. The corrosion survey indicates areas of pipeline corrosion.

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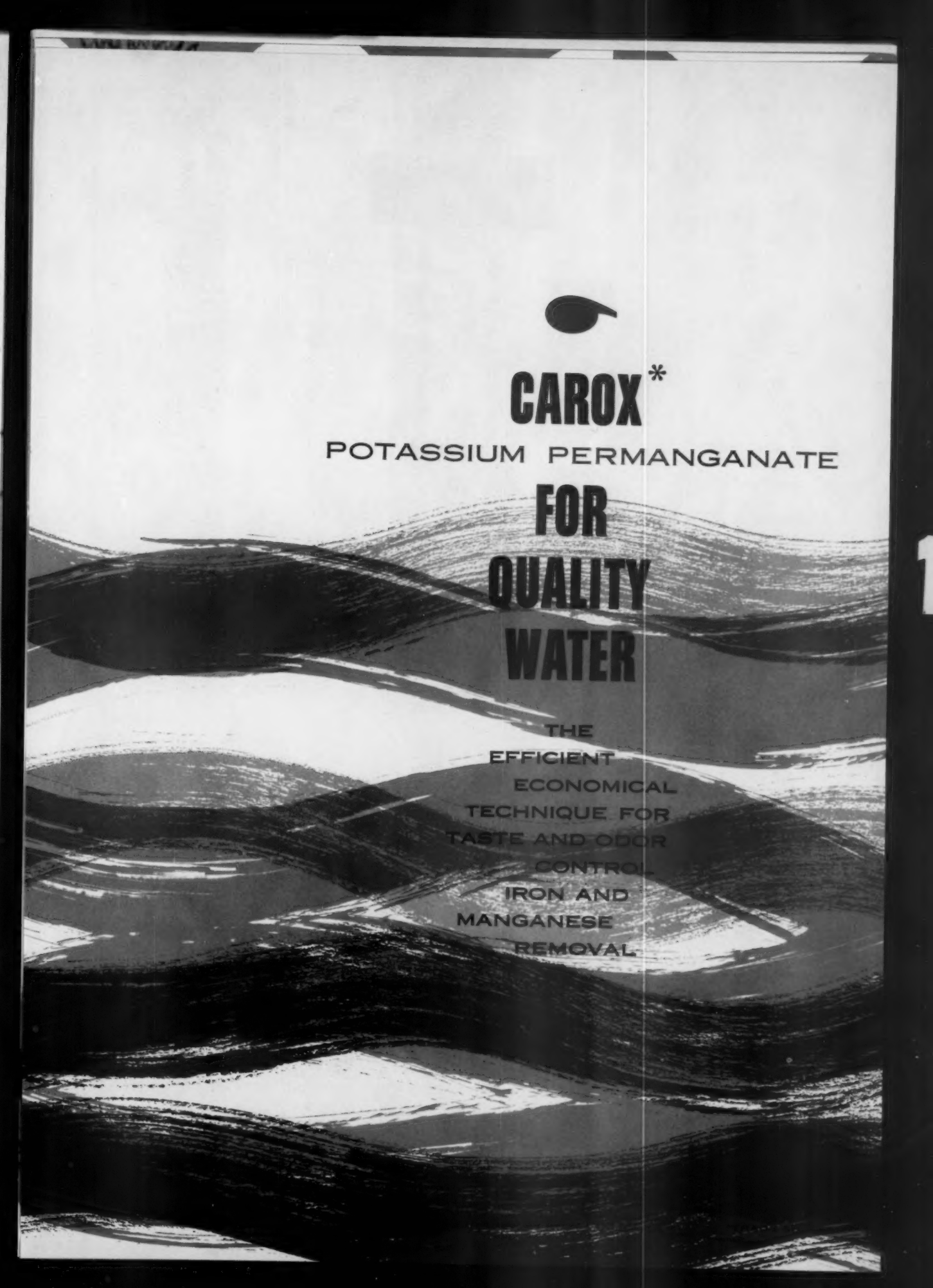
Table 2
Corrosion of Standard Iron Wire
By Waters Taken from the High Service District
of the West Andover Water Distribution System
(Sampled 14 March, 1960)

Sampling Point Number	No. of Miles from Raw Water Source	Location	Manometric* Iron, mgms@ t = 240 hrs.	Phenanthroline Test Iron, mgms (Supernatant from Warburg flasks)
1	0	Haggetts Pond—100' fr. shore[a]	4.58	4.89
2	0.38	Haggetts Pump Station	0.95	0.96
3	1.70	Base of Wood Hill—Haggetts Pond Rd.	3.56	3.97
4	2.30	Haggetts Pond Rd.—100' fr. High Plain Rd.	0.98	1.13
6	2.84	Pleasant St.—Dead End—Kearns	1.04	1.14
5	2.98	High Plain Rd.—Dead End—Boutwell	0.54	0.66
7	3.13	River Rd.—1000' fr. Boutwell	1.56	1.87
8	4.03	River Rd.—1000' fr. Chandler Rd.	1.71	2.03
9	4.97	Chandler Rd.—Lynch	8.00	9.22
10	5.30	River Rd.—1000' fr. North St.	7.88	7.22
11	6.44	North St.—1500' fr. Webster St.	2.94	3.42
12	7.75	Greenwood Rd. (Miller)	4.12	4.68
15	7.78	Corner of Beacon and Chandler Rd.	4.76	5.42
13	8.44	Greenwood Rd.—1500' fr. Lowell Rd.	4.11	4.69
14	8.76	Corner High Plain Rd. & Rolling Ridge Rd.	2.54	2.62

* Computed from observed oxygen uptake values (Warburg apparatus) and substitution in the equation: $2\ Fe + 1.5\ O_2 + xH_2O = Fe_2O_3 \cdot xH_2O$
[a] Chopped through 10-inch ice cover.


CAROX*
POTASSIUM PERMANGANATE
FOR
QUALITY
WATER
THE
EFFICIENT
ECONOMICAL
TECHNIQUE FOR
TASTE AND ODOR
CONTROL
IRON AND
MANGANESE
REMOVAL

Potassium permanganate is a dark purple crystalline chemical with remarkable oxidizing properties. These properties make it chemically effective for taste and odor control in water treatment, as well as for iron and manganese removal; and its economy and ease of handling recommend it as the preferred method for dealing with these problems wherever they exist.

The literature on water treatment includes many references to the successful use of potassium permanganate on an experimental or limited basis. Over the past several years, however, its usage has moved from the laboratory to the field. CAROX* Potassium Permanganate is now being used to solve taste and odor problems and to remove iron and manganese in many water supplies.

CAROX Potassium Permanganate is a product of Carus Chemical Company, Inc., LaSalle, Illinois, Carus Chemical has constantly improved its manufacturing techniques and capacities; and its experience of almost half a century assures the user of adequate supplies and exacting quality control. CAROX is available nationwide through local chemical distributors.

* Trade Mark for $KMnO_4$ manufactured by Carus Chemical Company, Inc., under Patent Nos. 2843537, 2908620, 2940822, 2940823, others pending.

CAROX REMOVES

musty
earthy
woody
moldy
swampy
grassy
fishy

TASTES & ODORS

CAROX DESTROYS

hydrogen sulfide
organic acids
mercaptans
acrylates
esters
aldehydes
ketones
nitriles
olefins
alcohols
organic herbicides, fungicides, insecticides
fish poisons

CAROX

POTASSIUM PERMANGANATE

for Taste and Odor Control

CAROX treatment in conventional water systems effectively and economically removes unpleasant tastes and odors. It works quickly and efficiently, via both oxidation and adsorption, to help provide safe, pure, palatable water. CAROX will solve the problems caused by hydrogen sulfide, industrial wastes, decayed vegetation, algae, and actinomyces.

Unlike many other chemicals for dealing with tastes and odors, CAROX Potassium Permanganate is safe and easy to handle, and does not create new taste and odor problems in solving old ones. In addition, it effectively minimizes quantity requirements on other chemicals.

CAROX treatment in conventional water systems prevents annoying red, brown, and black stains on bath and kitchen fixtures, laundry, or in industrial end-products, and iron deposits in pipe lines.

When CAROX is added to raw water which contains organic and soluble iron and manganese, oxidation begins immediately. All of the dissolved iron and/or manganese are rapidly converted to their corresponding insoluble oxides, which are readily removed by coagulation, sedimentation, and/or filtration.

CAROX offers several advantages for iron and manganese removal over alternate techniques. It works rapidly and *completely*, and does not cause side problems, such as poor coagulation and incomplete oxidation. In addition, it provides complete safety in handling, and its use will generally result in over-all *savings*.

HOW TO USE CAROX POTASSIUM PERMANGANATE

YOU can put CAROX right to work in your plant. No special equipment is required.

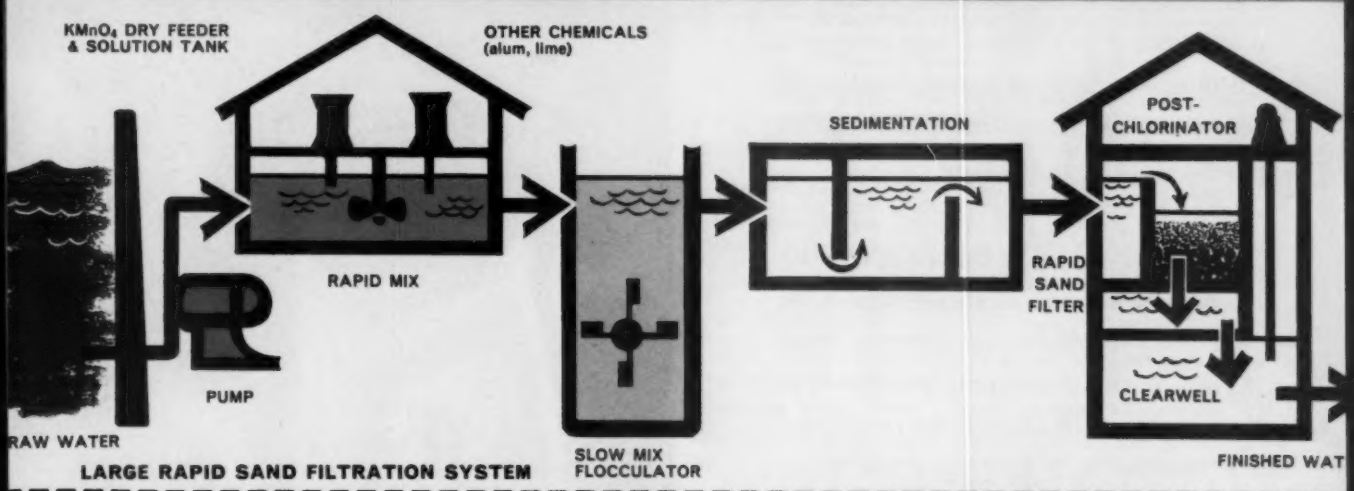
CAROX is compatible with chlorine, lime, alum, and ferric sulfate. It must be consumed before copperas (ferrous sulfate) and activated carbon can be added.

In water systems employing pre-treatment, coagulation, sedimentation, and filtration, CAROX is added during pre-treatment. Potassium permanganate in solution can be added either before, during, or following chlorination, depending upon the contaminants and the system.

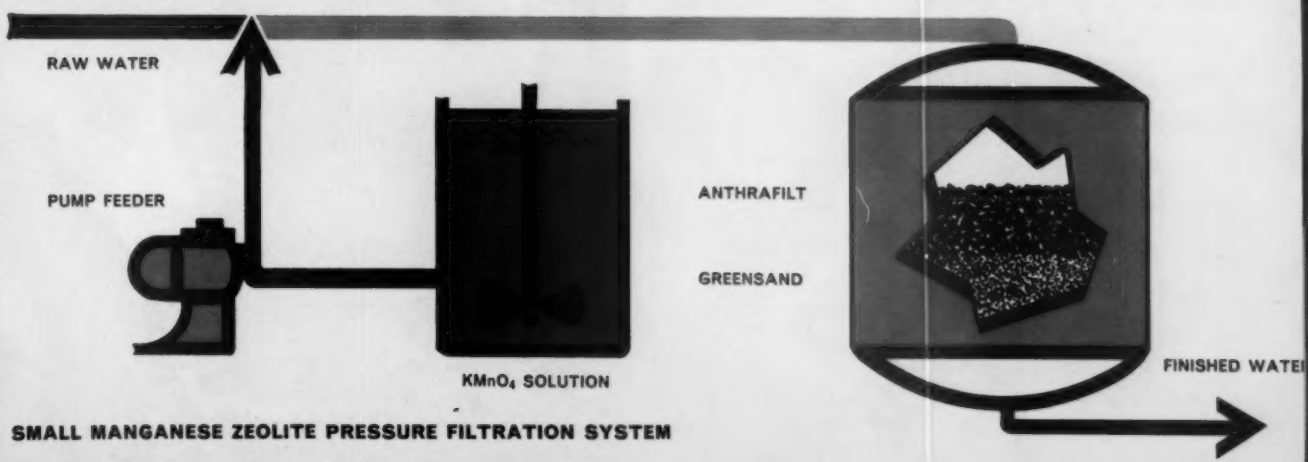
THE oxidizing effects of the potassium permanganate will not only eliminate iron and manganese and destroy tastes and odors; they will also reduce the chlorine demand of the raw water. As CAROX works, it forms manganese dioxide (MnO_2), a coagulant aid which can cut coagulant requirements as much as 60%.

In small systems employing manganese zeolite or manganese-treated greensand pressure filters, the CAROX solution is fed into the raw water. It rapidly oxidizes soluble iron, manganese, hydrogen sulfide, etc., for removal by the filter.

A SLIGHT excess of potassium permanganate keeps the mineral bed perpetually regenerated. Down-time is minimized, and is limited to back-washing. The mineral bed serves as a buffer, since it has a demand for potassium permanganate, and soluble iron, manganese, and hydrogen sulfide.



LARGE RAPID SAND FILTRATION SYSTEM



SMALL MANGANESE ZEOLITE PRESSURE FILTRATION SYSTEM

ADDITIONAL ADVANTAGES OF CAROX POTASSIUM PERMANGANATE

BESIDES its effectiveness in controlling tastes and odors and removing iron and manganese, potassium permanganate has decided biocidal properties. As has been noted, its use results in the formation of manganese dioxide, an efficient, adsorbent and effective coagulant aid. CAROX minimizes the requirements for other chemicals.

CAROX is safe and easy to handle. It requires minimum storage space, and its stability is such that it can be kept indefinitely. (It should be stored in a cool dry place, in closed containers.) Dry or in solution, it is odorless, non-corrosive, and does not produce harmful vapors. It requires no special materials of construction for storage or handling.

THE use of CAROX to provide quality water is almost certain to be less expensive (and more effective) than alternate methods of coping with the same water problems. Although the permanganate demand will vary with the water supply, it will never exceed theoretical amounts, and will generally be considerably less. Many communities have found that the introduction of CAROX treatment has resulted in effective savings (by reducing expenses for other chemicals), even where there had been no previous attempt to solve the problems for which it was introduced. Using CAROX doesn't cost—it pays!

CAROX

AND THE COMMUNITY

EVALUATION PROCEDURES FOR POTASSIUM PERMANGANATE IN WATER TREATMENT

PREPARATION OF POTASSIUM PERMANGANATE SOLUTIONS

In the absence of laboratory facilities, the tests described below can be conducted using commonly available containers and measuring devices. The following approximations will provide sufficiently accurate results:

1 liter—1 quart 15 ml.—1 tablespoon
500 ml.—1 pint 5 ml.—1 teaspoon
30 ml.—1 ounce 1 ml.—12 drops (from an ordinary eyedropper)

Equivalents using these measuring devices are indicated in parentheses throughout the procedures.

STOCK SOLUTION (1%)

Use an accurately weighed 5 gram $KMnO_4$ sample (pre-weighed and packaged 5 gram samples are available without charge from Carus Chemical Company, Inc., or any of its distributors). Dissolve the sample in distilled water, with vigorous agitation, in a 500 ml. volumetric flask (1 pint container). Be sure that all of the $KMnO_4$ is dissolved; then dilute to volume. (Fill pint jar with distilled water.)

STANDARD SOLUTIONS

Standard Solution "A" (for water of low contamination)

Pipette 1 ml. of the 1% stock solution into a 100 ml. volumetric flask (or 1 teaspoon of the 1% solution in a 1 pint container) and dilute to volume. One ml. (12 drops) of this solution added to a 1 liter (1 quart) raw water sample is equivalent to 0.1 ppm (parts per million) $KMnO_4$.

Standard Solution "B" (for highly contaminated water)

Pipette 10 ml. of the 1% stock solution into a 100 ml. volumetric flask (3 tablespoons and 1 teaspoon of the stock solution in a 1 pint container) and dilute to volume. One ml. (12 drops) of this solution added to a 1 liter (1 quart) raw water sample is equivalent to 1.0 ppm $KMnO_4$.

PROCEDURE

Determine approximate permanganate demand of raw water

Titrate a 1 liter (1 quart) raw water sample with *Standard Solution "A"* to a ten minute pink end point, (making sure that the color does not disappear in less than 10 minutes).

Example: A 1 liter (1 quart) raw water sample required 15 ml. (180 drops or 3 teaspoons) of *Standard Solution "A"* to produce a 10 minute pink end point. Thus, the demand was approximately 1.5 ppm. If more than 50 ml. (10 teaspoons) of the *Standard Solution "A"* was required, use *Standard Solution "B"* and repeat the procedure.

JAR TESTS

(for determining the amount of $KMnO_4$ required to oxidize soluble iron, manganese, and taste and odor producing compounds)

Prepare six 1 liter (1 quart) raw water jar samples, simulating plant practice in pre-treatment regarding time, mixing, pH adjustment, and coagulant (lime, alum, etc.), but eliminating activated carbon, chlorine, chlorine dioxide, etc. Add $KMnO_4$ *Standard Solution "A"* or *"B"* in approximately equal increments approaching the quantity indicated by the approximate demand previously determined, with at least one sample having more $KMnO_4$ added than the indicated demand.

Example: Approximate demand was 1.5 ppm, as in the first example above. Therefore, add 0.5, 0.75, 1.0, 1.25, 1.50, and 1.75 ppm $KMnO_4$, respectively.

Mix, flocculate, coagulate, and settle the samples to simulate plant conditions. Duplicate plant hold-up time for best results. If you use pressure filters, mix for a period of time comparable to the time interval from point of application of $KMnO_4$ solution to top of filter bed.

Decant and filter all samples having no pink color (pink color indicates overdose of $KMnO_4$) using either filter paper or a laboratory sand filter (sand filters are more efficient than filter paper, particularly for colloidal particles). Analyze the samples with no pink color for iron, manganese, and tastes and odors as follows:

ANALYZE FOR IRON AND MANGANESE

Use *Standard Methods** or suitable commercially available test kits. The sample using the least amount of $KMnO_4$ and having residual iron and manganese at acceptable levels indicates the required $KMnO_4$ dosage. (Fe^{++} residual should be <0.05 ppm; Mn^{++} residual should be <0.05 ppm.)

Example:

Sample Number	1	2	3	4	5	6
ppm $KMnO_4$ Added	0.5	0.75	1.0	1.25	1.50	1.75
Color	no pink	no pink	no pink	no pink	pink	pink
Residual Fe^{++}	0.18	0.10	0.06	0.00	discard	discard
Residual Mn^{++}	0.12	0.10	0.07	0.04	discard	discard

Sample No. 4 indicates $KMnO_4$ dosage is approximately 1.25 ppm.

DETERMINE TASTES AND ODORS

Precautions: The analyst should avoid smoking or the consumption of highly seasoned foods prior to testing. In addition, the use of scented soaps, shaving lotion, perfume, etc. should be avoided. Odor-free glassware and odor-free water should be used throughout the determinations.

Test for Odor

Place a 200 ml. (approximately 6½ ounce) sample in a 500 ml. Erlenmeyer flask (a pint jar). Only those samples which show no pink color need be tested. The test may be carried out either hot or cold, as desired. Cold odors are most conveniently detected at 20-25° C. (68-77° F) (room temperature), hot odors at 58-60° C. (136-140° F). Cover the container and shake it lightly, then smell to determine if odors are present. Compare it with some odor-free water. The sample that has no odor indicates the least amount of potassium permanganate required for production of odor-free water.

Test for Taste

Use exactly the same techniques for tastes as for odors, except that the samples are tasted instead of smelled. It is advisable to rinse the mouth with taste-free water between samples. Do not swallow any of the water samples tasted.

THRESHOLD TESTS

For reference purposes it is advisable to carry out tests to determine the threshold number of both raw and treated water samples. The methods described below are discussed in detail in *Standard Methods**.

Threshold Odor: Place a 200 ml. (6½ ounce) sample in a 500 ml. Erlenmeyer flask (1 pint jar). The test may be carried out either hot or cold, as desired. Shake the flask and smell the odor. If a characteristic odor is detected, use 100 ml. (3¼ ounces) of the sample and dilute to 200 ml. (6½ ounces) with odor-free water and repeat the test. This procedure is repeated until the odor disappears. The threshold odor number is equal to the total volume of water divided by the volume of *sample* which produced the last detectable odor.

Example: When 12.5 ml. of *sample* was diluted to 200 ml., the odor was just faintly detected. $\frac{200}{12.5} = 16$ = threshold odor number.

Threshold Tastes: Threshold tastes are determined in the same manner as threshold odors, except the samples are tasted instead of smelled. CAUTION: Do not taste polluted, untreated water samples.

**Standard Methods for the Examination of Water, Sewage, and Industrial Wastes.* 11th ed., pp. 257-259, prepared and published jointly by A. P. H. A., A.W.W.A., and F. S. I. W. A., New York (1960).

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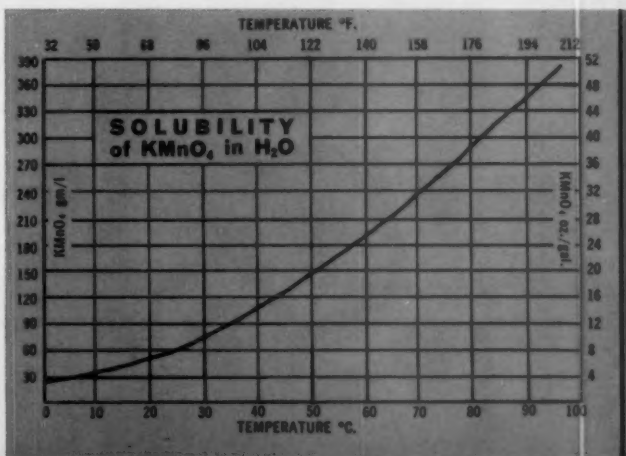
TEMPERATURE °F.
32 50 68 86 104 122 140 158 176 194 212
SOLUBILITY
of KMnO4 in H2O
KMnO4 gm/l
KMnO4 oz./gal.
TEMPERATURE °C.
0 10 20 30 40 50 60 70 80 90 100

TABLE OF EQUIVALENTS
Parts per million—pounds per million gallons

ppm	lb./mg.
0.1	0.834
0.2	1.69
0.3	2.52
0.4	3.38
0.5	4.17
0.6	5.04
0.7	5.84
0.8	6.68
0.9	7.51
1.0	8.34
2.0	16.68
3.0	25.02
4.0	33.36
5.0	41.70

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The Water Economy and Desalting of Sea Water

by ABEL WOLMAN, Professor of Sanitary Engineering, The Johns Hopkins University Baltimore, Maryland

■ THE CALIFORNIA Institute of Technology on May 5 and 6, 1960, held a Symposium in Pasadena, California, on the "Desalting of Water." At the conclusion of these sessions the present author was requested to prepare a general summary of the discussions. In that summary an evaluation of the impact of desalting of sea water on the water economy of the United States was requested.

No arrangements had been made for the publication of any of the discussions at this Colloquium. Permission has been granted, therefore, by the Institute of Technology to present and publish the results of these findings. The present paper represents an extension of the remarks presented in Pasadena, by information and data subsequently accumulated by the author.

The interest in the subject of desalting of saline waters developed during the last 5 years stems from the general assumption that our country and many other parts of the world will be confronted in less than a decade with severe water restrictions and availabilities for our total needs. It is important, therefore, as a setting for any discussion of the impact of desalting on our water economy, to determine whether these stresses in water availability and use are in fact as distressing as many would lead us to believe.

Water Requirement Prospect

It has been generally estimated that by 1980 the total withdrawals from stream flow in the United States of North America for purposes of irrigation, manufacturing, mining, steam electric power and municipal uses will approach some 560 billion gallons per day. The major withdrawals, of course, will be for irrigation, manufacturing and steam electric power.

That these figures should not cause too much alarm, it should be remembered that the major part of these withdrawals are returned to the streams for subsequent re-use. More accurate and less alarming figures indicate that the actual consumptive use in this same country will rise to 1980. This latter figure incidentally, will represent somewhat less than 11 per cent of the average stream flows available.

One should not forget, however, that water availability is a function of place, time and climate. Average figures, therefore, tend to conceal that some areas in the United States will encounter water difficulties earlier and to a greater degree than others. Desalting hence does have a significance, the magnitude of which will appear in later discussions. It is extremely doubtful that scarcity of water on a broad basis, at least in the United States, will impose a serious restriction on our ultimate growth.

Competition for water in the open market will undoubtedly parallel the past. Existing supplies may be diverted from current users to higher value uses. Some of this evolution has already taken place, of course, in the shifting from irrigation water to industrial water in many parts of the United States.

Some Definitions in Desalting

Much loose talk has been indulged in with respect to desalting processes. The methods of removal of soluble minerals from various concentrations in water have not been sharply delineated in much of the literature. This confusion of concentrations of salts and methods of desalting or demineralization has resulted in difficulty in identifying actual costs.

For the purposes of this discussion the classification of waters shown in Table 1 is adopted.

Several years ago official agencies in the Federal Government had suggested that production costs of desalting processes should aim to reach certain price goals, namely, some 38c per thousand gallons for municipal or domestic waters and 12c per thousand gallons for irrigation water uses. Such goals were to be compared with production costs for desalting, without the additional cost for distribution to the points of actual use.

In recent years less and less emphasis is being placed officially upon these goals, because they have become somewhat embarrassing, particularly in relation to agricultural uses. This embarrassment arises from the fact that, although the production cost of desalting or demineralizing water has declined appreciably in the last 3 or 4 years, it is improbable that the figure quoted above for irrigation use will be reached in the foreseeable future.

When considering production costs noted later herein for comparison with fresh water costs, it should be emphasized that the former in general will necessitate higher pumping lifts to the consumer from sea level elevations, will not include the cost of distribution and multiple re-pumping into service zones, will provide for no filtration or other treatment costs, no cost of waste disposal, no holdover storage to meet the variable demands of consumers, and no research or development costs.

Table 1

Characteristics of Mineralized Waters

Description	Dissolved Solids—P.P.M.
Brackish	1000 - 3000
Moderately Saline	3000 - 10000
Sea Water	33000 - 36000
Brine (Dead Sea, Salt Lake, etc)	36000 plus

Experience to Date

Sea Water Conversion: Information now available on sea water conversion indicates clearly that the bulk of these operations in desalting is generally accomplished by one or

Presented before the Eastern Water Company Conference, Atlantic City, N. J., October 14, 1960.

another form of distillation. Some 16 such plants are now in operation throughout the world, in the range from 100,000 to 3,500,000 gallons per day. They have an aggregate capacity of somewhat less than 15 million gallons a day.

Evidence presented in considerable detail at the Pasadena meeting discloses briefly the following data.

In the Aruba plant on the Carribbean Sea, the cost of production per thousand gallons apparently is between $1.25 and $1.75.

In the Morro Bay power plant of the Pacific Gas and Electric Company, the cost of desalting per thousand gallons is $2.50 when the plant is running at full capacity.

In Kuwait, adjoining Saudi Arabia, the Kuwait Oil Company is producing fresh water from the Arabian Gulf sea water by evaporation. Unfortunately, no cost data are available for this plant, because of the major difficulties in bringing it into complete and successful operation now prevailing. The costs are undoubtedly in excess of $1.00 per thousand gallons.

At the Oxnard plant of the Southern California Edison Company, a pilot plant for desalting sea water is in operation by flash evaporation. No definitive costs on this plant are yet available.

Even with these limited observations, one might conclude that the production costs in the late 1930s of $4.00 to $5.00 per thousand gallons have been materially reduced in actual operation to something approximating $2.00. It is the hope of the official agencies in the Federal Government dealing with these operations that newer installations, with cheaper successful handling of scale and modifications in process, should result in the next 5 or 10 years to a production cost of fresh water from the sea of about $1.00 per thousand gallons or $326 per acre-foot.

Demineralization of Brackish Waters: A number of methods have recently come into action for the removal of soluble mineral salts from waters containing very small fractions of the amount in sea water, namely somewhere between 1500 and 2500 parts per million of soluble salts.

The work done with South African mine wastes, frequently noted as desalting of sea water, of course, represents no such parallel. The successful application of membrane processes to demineralizing mine wastes in South Africa is resulting apparently in production costs of somewhat less than 50c per thousand gallons. The raw water falls within the definition of brackish water when the concentrations of minerals are noted.

The Coalinga, California, experience has also been confused with the desalting of sea water. The Coalinga plant is demineralizing water having a concentration of dissolved salts somewhat less than 2500 ppm, of ground water origin. Its present production costs are $1.43. This is compared with their former cost of carting water into the community at a cost of $7.05 per thousand gallons. The saving is obviously great. Further experience with the process may result in reducing the production cost to something less than 80¢.

In Bahrein a similar process is in operation, with an estimated cost of production, at full capacity, of $1.27 per thousand gallons.

It is difficult to predict what the processes of demineralization of brackish water will ultimately develop. It is not overly optimistic to assume that with better equipment and more and more successful life for membranes, the production costs should approach 75¢ ($245 per acre-foot) or less.

These costs again do not include costs of wastes disposal and of distribution to the consumer both of which represent a considerable item.

Other processes for demineralization or for true desalting of sea water are for the most part still in pilot plant form. Any effort to prophesy their probable production cost, is certainly premature, in moving from the production of 15,000 gallons per day on a pilot plant process to 5 to 10 million gallons a day for major water users. Some believe that such conversion costs by freezing processes may, in the case of brackish water, approach $1.00 per thousand gallons, although these processes are still in only laboratory or pilot plant stage.

Economic Comparisons

When one compares the present and prospective production cost for fresh water versus demineralized water, it should be recalled that the consumer will normally choose those waters which are cheapest for equal quality. In areas where fresh water is not easily available, recourse will be had, if necessity arises either to brackish or sea water, if these in turn are at hand. The water becomes available when it is worth producing for particular purposes. Choice of source and payment for it then become in fact true economic decisions.

For purposes of comparison, therefore, one must review the usual costs of producing water by municipalities and industries. Many of these costs are available in considerable detail and their exploration is not undertaken here. It may be said, however, with considerable accuracy that industrial and municipal production costs rarely exceed 25c per thousand gallons. In the Los Angeles area fresh water production costs average 3 to 20c or $10 to $70 per acre-foot, even with the very long aqueduct delivery there installed.

In the Baltimore area the production cost for municipal water is less than 10c, exclusive of filtration and distribution.

In some instances elsewhere, the actual delivery cost of raw fresh water supplies, including all aqueduct costs, but excluding treatment, is less than 20c per thousand gallons.

Even the relatively expensive Colorado River water produced by the Metropolitan Water District of Southern California, with a total lift of 1600 feet, costs less than $30 per acre-foot delivered.

It is striking that the cost of water at the Delta under the California State Multiple-purpose Program is only 1.075 cents per thousand gallons ($3.50 per acre-foot). S. B. Morris, in this connection, pointed out[1] that irrigation water costs delivered to the farmer's headgate are generally of the order of $1.00 to $10.00 per acre-foot (0.307 to 3.07 cents per thousand gallons). For limited areas of very high value crops these costs may reach as high as $40.00 per acre-foot (12.28 cents per thousand gallons).

Reasonable Conclusions

The data here presented make it clear that it would be a grave mistake to place any degree of hope on

[1]The Need for Water—The Western Picture. Samuel B. Morris. Unpublished paper presented before the Pasadena colloquium on the Desalting of Water, May 5, 1960.

finding an early economic solution to water problems in the desalinization of sea water, so that it becomes a major competitor of large fresh water requirements. With respect to irrigation in any feasible fresh water project it is equally clear that such a project cannot with present evidence be economically challenged by any demineralizing process now known.

Even in the Pacific Coast states, where water shortages have been over emphasized in the public press, it is clear that fresh water can be made available for requirements after 1990 at a production cost which is extremely low.

Samuel B. Morris[2] at the Pasadena Conference stated clearly "pointing to increasing quantities of water used by our rapidly increasing population is not an adequate appraisal of the future need for recovery of fresh water from salt and saline waters. Rather, a more specific approach, weighing the local needs and ability to pay, with alternative sources of water available, is necessary."

The present author has estimated that by 1965 the world wide use of land sea water distillation plants may account for as much as 50 million gallons a day. Those for the conversion of brackish waters may account for an additional 20 million gallons a day. When these amounts are compared with the billions of gallons necessary throughout the world, it is conservative to assume that the total effect of desalinization and demineralization on the national and international water economy will be minor.

Before one is accused, however, of standing in the way of progress, the author hastens to emphasize the great importance of such processes in many scattered areas of the United States and elsewhere. In those regions both brackish and to a lesser extent sea water may be converted, simply because no other cheaper or any sources of water are available. These facts point to the undoubted desirability of pursuing, with increased energy and money, the research in the basic physical chemistry of highly mineralized water. It is gratifying that the Federal Government has recently recognized that only minimum amounts of money have been spent hitherto in such research and has provided additional funds for the immediate future.

Of equal importance is the necessity for moving forward with rapidity in engineering design and development in order to continue to reduce the very wide gap between the theoretical minimum power requirements for desalting and the actual plant accomplishments.

Cheaper Alternatives in Water Management

In the discussion of the competitive costs of desalinization and fresh water production, one cannot escape the conclusion that, where fresh water becomes scarce, cheaper alternatives to demineralization are often available. These alternatives usually come into play when water is difficult to get, costs for development rise to uneconomic levels and geographical proximity favors re-use of wastes. Examples of such circumstances are in Aruba, Southern California and Bethlehem Steel Company at Balitmore, Maryland.

It should be remembered, of course, that the re-use of natural waters is well-nigh universal. That it will be expanded in undoubted, as improved and cheaper modes of waste treatment and water purification are developed. Here is a most fruitful field for research and development.

Elaboration of the possibilities of re-use, as a major future source of required water is reported in detail in a document[3] submitted to the Senate Select Committee on Water Resources. A few examples are culled from this document to illustrate the potentialities already referred to above.

(a) Bethlehem Steel Company at Sparrows Point, Maryland. Direct re-use for industrial purposes of completely treated sewage plant effluent from Baltimore City. In use since 1942, rising from 25 to 115 m.g.d. in 1960. Cost of delivery, including fixed charges on two pipe lines of 26,000 feet in length, pumping stations and treatment plants, is approximately 3.5c per thousand gallons.

(b) Savings in industrial use. The comparisons shown below give some indication of before and after conservation uses, where reduction in use becomes profitable. The figures are in gallons per ton.

Industry	Before Conservation	After Conservation
Steel	55,000	1500 - 3000
Paper	7000 - 10,000	3000 - 4000
Kraft Pulp	45,000	9000
Newsprint	26,000	6000
Cannery	2500	1200

(c) Savings in irrigation water. Uses per acre in the United States are often excessive. The Department of Agriculture estimates that, by the year 2000, savings by more efficient irrigation practices may run as high as 50 million acre-feet per year.

(d) Control of useless phreatophytes, water loving plants, may save some 6 million acre-feet per year.

(e) Underground storage of surface waters which now go to waste.

(f) Demineralization of treated municipal sewage. Sea water contains some 35 times as much dissolved solids as does sewage. The removal of dissolved solids from the latter is undoubtedly much cheaper than from sea water.

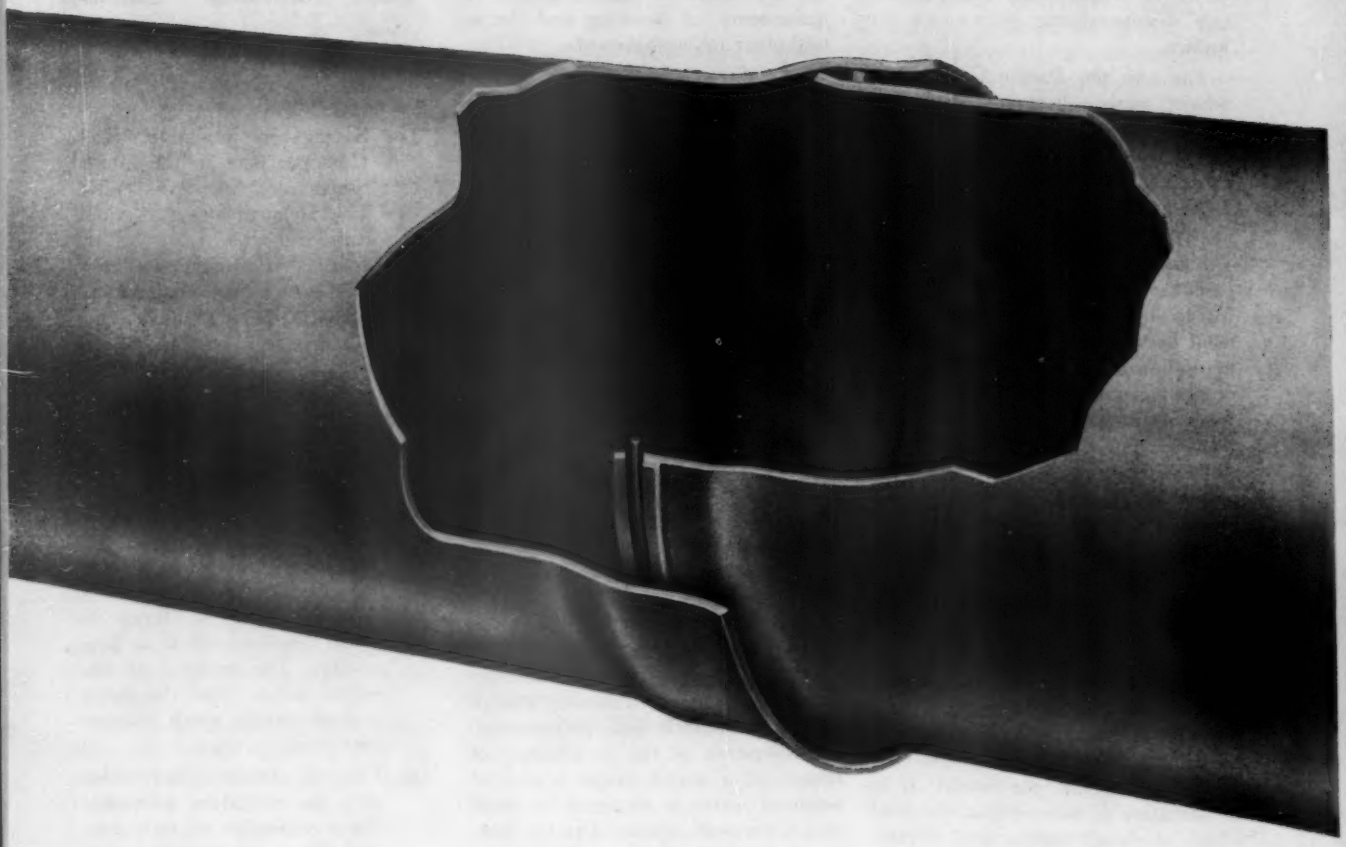
(g) Use of sewage plant effluents for irrigation purposes. Many examples of such controlled use are available, with necessary and most careful attention to the public health implications. A most recent example, even though on a relatively modest scale and after some six years of experiment, is in the Talbert Valley in Southern California. The farms use the liquid from the primary sewage treatment plant of the Orange County Sanitary District. Some 2800 acres are now being irrigated from this source at about $6 per acre-foot.[4]

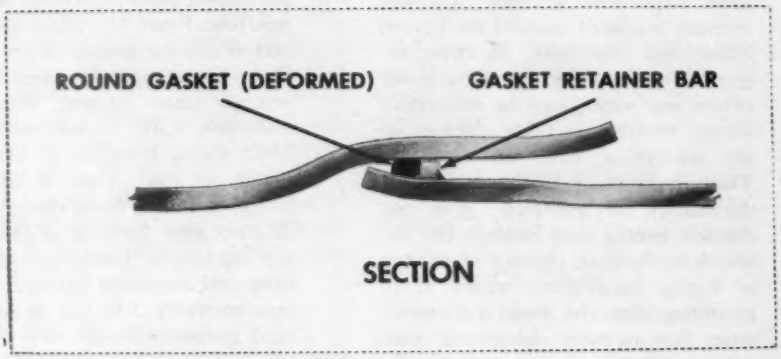
None of these examples produce *additional* water, but they have high significance in stretching our water resources over a greater population, if and as required.

[2]The Need for Water—The Western Picture. Samuel B. Morris. Unpublished paper presented before the Pasadena Colloquium on the Desalting of Water, May 5, 1960.

[3]Present and Prospective Means for Improved Re-Use of Water. Report to the Senate Select Committee on National Water Resources, Committee Print No. 20, March 1960. Prepared by E. F. Gloyna, J. B. Wolff, J. C. Geyer and Abel Wolman.

[4]Organizing a Sewage Effluent Utilization Project. Paul W. Travis. Public Works, September 1960, p. 119.

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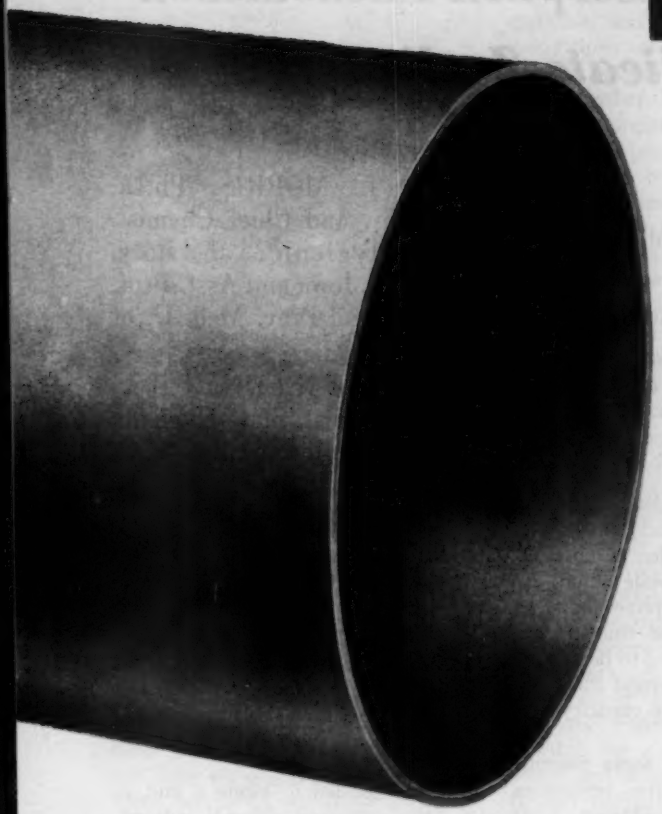

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Of more than passing interest is this report on . . .

Fluoride Adsorption and Resorption Phenomenon *of Sodium Aluminum Silicate Zeolites*

by R. L. MORRIS, Ph.D., Asst. Dir. and Chief Chemist, State Hygienic Laboratory, Iowa City, Iowa and Asst. Prof. Hygiene and Prev. Med. U. of Iowa,
JOSEPHINE CERNY, B.S., Assoc. Chemist, State Hygienic Laboratory, Iowa City, Iowa and
D. W. EBERT, B. S., Assoc. Chemist, State Hygienic Laboratory, DesMoines Branch, DesMoines, Iowa

RESUME: Careful investigation has shown fluoride loading and unloading during cation exchange cycles of domestic softening units. Studies show resorptive phase may be normally 10-15 per cent of total cation exchange cycle. Attempt is to provide information about incidence and mechanism of reduced fluoride content.

■ ONE OF THE important requisites for approval and operation of a water fluoridation installation by many State Health Departments is the regular and continual submission of plant and distribution samples to the State Laboratory for referee analysis of fluoride content. The specimens are usually submitted on a weekly schedule and are taken on a split sample basis from various locations in the municipal distribution system. The local approved laboratory is usually required to perform daily fluoride analysis on the plant effluent and at least one distribution system sample.

A distribution sample received by our laboratory from a fluoridated water supply gave 5.5 ppm fluoride ion by both non-distillation and distillation procedures [1] which represents an increase of 4.5 ppm above the amount shown to exist in the plant effluent by calculation and actual analysis. This sample was a softener effluent taken from a source where a freshly regenerated mineral zeolite cation exchanger had been recently installed. It was subsequently determind by distillation fluoride analysis [2] that this same phenomenon existed when other freshly regenerated exchangers were checked in this same city. Also, it was shown that some installations evidenced no effect on fluoride content, while others exhibited a major absorptive ability as regards fluorides. The fluoride adsorption effect appeared to be of long duration extending beyond the point where cation exchange capacity was exhausted.

Table I illustrates these fluoride additive and extractive tendencies under actual field conditions. Unit #291 indicates a resorption of fluoride extending for at least nine days while softening only residential hot water, and Unit X reduced to normal and into the fluoride adsorptive range in approximately 500 gallons.

The exchangers used in this city were backwashed after exhaustion and then regenerated by 100 lbs. of salt in solution passed through the line of units hooked in series. The salt was placed in a solution pot and water was passed through under pressure to effect solution. Concentration of the brine varied progressively from strong to weak during the brining period. The first softener in line was subjected to 100 lbs. of salt and the subsequent units received progressively less salt. The units were rinsed in series until the last softener showed near zero hardness, and then they were used as replacements for exhausted exchangers on a periodic basis.

It was decided to locate a unit in operation showing fluoride adsorption for detailed laboratory and pilot plant study. Unit #22 was found to be producing the desired results after three weeks of actual residential service. Influent fluorides of 1.0 ppm were being reduced to 0.4-0.6 ppm by passage through the unit. This unit was found to be charged with mineral zeolite having a heavy brown film deposited on and within the grains. The mineral was carefully removed from the metal cylinder without washing for further exploration.

Salt regeneration studies showed that large amounts of iron (50 ppm) and up to 7.0 ppm fluoride ion were present in the early rinse stages after use of concentrated brines. Use of more dilute brines did not produce the iron and fluoride leaching to

Table 1

ADDITION AND EXTRACTION OF FLUORIDE ION BY MINERAL ZEOLITES IN FIELD SERVICE SERIES REGENERATED

DATE	TYPE OF SERVICE	Influent (F-)	Effluent (F-)
12-10	Residence A	1.1	1.2
1-21	Residence B	1.0	5.5
1-21	Residence C	1.2	2.0
2-10	Residence D	1.2	0.2
2-21	Residence E	1.1	0.4
2-10	Intermittant Operation (#291)	1.1	4.2
2-13	Intermittant Operaton (#291)	1.0	5.0
2-15	Intermittant Operation (#291)	1.1	5.2
2-16	Intermittant Operation (#291)	1.05	5.5
2-19	Intermittant Operation (#291)	1.1	3.6
2-19	Intermittant Operation (#219)		3.1
2-19	Intermittant Operation (#291)		3.2
2-19	Intermittant Operation (#219)		3.2
	(Unit X Continuous Operation)	1.2	9.0
	92 gallons	1.2	3.4
	195	1.2	2.1
	285	1.2	1.7
	385	1.2	1.4
	530	1.2	1.0
	800	1.2	0.8
	1115	1.2	0.75
	2000	1.1	0.7

Continuous operation of unit X was at 1½ gals./min./cu. ft.

nearly such an extent. Successive concentrated brinings tended to remove much of the iron film and markedly reduced the tendency of the zeolite to give up fluoride ion to water passed through it. Usually three regenerations with concentrated brine were sufficient to rejuvenate the contaminated zeolite to the point where no significant fluoride resorption or adsorption was evidenced.

Adsorption studies on #22 zeolite are shown in Table 2 which illustrates the possibility that this phenomenon is an equilibrium in that fluorides are resorbed in the first sequence using water having 0.4 ppm as influent, while subsequent adsorption is accomplished using higher influent fluorides.

Solutions containing two, four and twelve parts per million fluoride ion were passed through this same 0.1 cu. ft. mineral bed producing effluents of acceptable fluoride quality as regards potable uses. Softeners from a series regeneration installation serving another city were also investigated and found to exhibit similar characteristics of absorption and resorption as shown in Table 3 Two privately owned softeners using silicious zeolite mineral and regenerated on a once-through basis with salt brine dumped to drain were also investigated in this second city. Evidence of both adsorption and resorption was demonstrated on these two units. It was felt that insufficient brine strength was used during regenerations to that the surface active film established over seven years of operation was not degenerated. The specificities of surface active film rupture by salt brines are being explored further.

The information in Table 4 indicates the possibility that this adsorption and resorption phenomenon can evidence itself under certain conditions on singly regenerated softeners as well as those regenerated in series.

The public health significance of the above data must be intelligently evaluated. There are several salient points involved here which should be stated and placed in their proper sequence of importance:

1. Most zeolite cation exchangers are installed to soften only the hot water, thereby keeping the amount of water actually ingested to a low level as most people use hot water only for coffee preparation or minor cooking needs. The most frequent exception to this occurs when high iron bearing waters are encountered. In these instances, it is common practice to pass the entire residential influent through the exchanger for iron removal and softening. Where municipalities partially soften by the lime soda process, many homes install cation exchangers to completely soften both the hot and cold supply. This is economic due to the long softening cycles obtainable on such low hardness influents.

2. Our data indicates that the resorptive phase is usually of relatively short duration, and fluoride levels above 1.5 ppm would probably occur for periods of time too short to have detrimental human effects. The duration of this resorptive phase is normally 10-15 per cent of the total cationic exchange cycle.

3. Cation exchangers using concentrated brine flushed directly to drain do not appear to exhibit this phenomenon according to our investigations to date. Also, only an occasional one of the series regenerated exchangers actually are proven fluoride donors. Statistically, the chances of any one family being subjected to excessive fluorides for any significant period is extremely small.

The position in the regeneration line of exchangers appears as though it might be one of the governing factors regarding the entrapment of the complexed fluoride ion. High salt concentration probably breaks the bond between the adsorbed fluoride ion and the activation surface film, allowing it to pass into adjacent exchangers and be readsorbed at lower salt concentrations. Discarding the regenerative brine and rinse fluid direct to drain from each individual softener probably would eliminate this condition.

The mechanism of activation and fluoride adsorption is not well understood at this time, but experiments to clarify this phenomenon are presently being conducted at our laboratories and show considerable promise. Iron concentration in the water being softened appears to be a critical factor in the establishment of the surface active film.

The absorption capacity of these field or synthetically activated zeolites could possibly be of value for removal of fluorides from water in areas where excessive concentrations of fluoride ion exists.

This is a preliminary report of field and laboratory findings and is being supported in part by a grant from the National Institutes of

Table 2

ADDITION AND EXTRACTION OF FLUORIDE BY ZEOLITE MINERAL #22 SERIES REGENERATED

INFLUENT F-	EFFLUENT F-	REMARKS
1.0	0.4	Residential Service (1 cu. ft.)
1.0	0.6	Residential Service (1 cu. ft.)
0.4	1.0	Laboratory (0.1 cu. ft.)
0.4	1.0	Laboratory (18 hrs.)
0.2	0.9	Laboratory (24 hrs.)
0.3	0.7	Laboratory (36 hrs.)
1.0	0.6	Laboratory (5 gals.)
1.0	0.6	Laboratory (10 gals.)
1.2	0.5	Laboratory Constant flow
1.0	0.7	Laboratory Constant flow
2.0	0.7	Laboratory 5 gals.
2.0	0.7	Laboratory 10 gals.
4.0	0.8	Laboratory 5 gals.
4.0	0.8	Laboratory 10 gals.
12.0	1.0	Laboratory 5 gals.
12.0	1.0	Laboratory 10 gals.

Flow rate of 1½ gals./min./cu. ft. maintained on all above experiments.

Table 3

ADSORPTION AND RESORPTION OF FLUORIDE ION BY SERIES REGENERATED ZEOLITE

DATE	TYPE SERVICE	INFLUENT	EFFLUENT	
10- 9-50	Residence (#1028)	0.65	1.8	+1.15
10-28-59	Residence (# 592)	0.7	0.25	−0.45
10-28-59	Residence (# 108)	0.7	1.15	+0.45
10-28-59	Residence (#1163)	0.8	0.35	−0.7
10-28-59	Residence (# 944)	0.75	1.45	+0.7
10-28-59	Residence (#1162)	0.75	0.15	−0.6

Table 4

ADSORPTION AND RESORPTION OF FLUORIDE ION BY INDIVIDUALLY REGENERATED ZEOLITE

DATE	PRIVATE SOFTENER	INFLUENT	EFFLUENT	
1-12-60	Residence "B"	0.95	2.1	+1.15
1-12-60	Residence "L"	0.9	2.0	+1.1
1-20-60	Residence "B"	0.9	0.45	−0.45
1-20-60	Residence "L"	1.0	0.4	−0.6

Health. A detailed report of synthetic activation studies will be published when completed.

Acknowledgement

The early recognition of this problem by Mr. Carl V. Blomgren, Regional Public Health Engineer, Iowa State Health Department and his valuable assistance in the preliminary field studies is hereby gratefully acknowledged.

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Detergents and Water Supplies*

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What Are They

■ THE WORD *detergent* when used as a noun is defined as a cleansing substance. In a broad sense water, abrasives, solvents, soap, and the so-called synthetic detergents are all cleansing substances and therefore are detergents. In this discussion we shall limit ourselves to ordinary soaps and the relatively new synthetic detergents.

Soap

First, let us consider what soap is so that we may better understand the difference from synthetic detergents. Fats react with alkalies to form soap, the reaction being termed *saponification*. Thus, soaps are salts of fatty acids. The ordinary toilet and laundry soaps of commerce are chiefly mixtures of sodium salts of stearic, palmitic, and oleic acids.

Soap is prepared commercially by boiling animal or vegetable fats with sodium hydroxide. The character of the soap formed is dependent largely on the fatty acids present in the fat. If a high percentage of sodium palmitate and sodium stearate are formed, the soap will be firm in texture. If, however, the soaps of unsaturated fatty acids are formed, such as sodium oleate, the soap will be soft and perhaps liquid at ordinary temperatures. This explains why many oils are unsatisfactory for soap making without first being saturated by hydrogenation. Soaps made from fatty acids with less than 12 carbon atoms in their configuration have low detergent properties but suds freely while those made from fatty acids containing more than 18 carbon atoms do not dissolve readily in water at ordinary temperature.

The sodium and potassium soaps are the only common soluble soaps. The other metallic soaps are insoluble in water. Thus, when a sodium soap is added to water containing calcium and magnesium ions, these metallic ions replace the sodium in the soap and insoluble calcium and magnesium soaps are precipitated effectively softening water by removal of the calcium and magnesium. The insoluble calcium and magnesium soaps cling to clothes in laundering and are difficult to rinse out. As a method of softening water, soap is expensive in comparison to ion exchange or lime-soda facilities and is very wasteful of soap because soap exerts no cleansing action until it has first reacted to remove all the calcium and magnesium ions from the water. In addition, the precipitated hardness in the form of insoluble soaps remains in the water.

Soaps other than sodium types are manufactured commercially. Soft or liquid soaps usually are potassium salts of the unsaturated fatty acids. The tincture of green soap used in hospitals is a solution of potassium soap in alcohol. Zinc stearate is a component of most talcum powders. Lead, manganese, and cobalt soaps are used in paints as driers. Some calcium soaps, which are soluble in oil, are components of lubricating greases. Ferric stearate is used as a leather dressing.

The packaged product commonly used in the household contains up to 90 percent of soap but also contains builders such as polyphosphates, dyes, and scents. The terminology would be more descriptive if these materials were referred to as soap detergents and thought of as a compound product containing soap as the surface-active agent and major constituent plus various builders included to enhance effectiveness and saleability.

Synthetic Detergents

Synthetic detergents are cleansers that contain one or more synthetic surface-active agents often referred to as *surfactants* instead of soap in their formulations. It must be realized that while there are a vast number of synthetic surface-active compounds available in commerce not all are ideal for household use.

In general, surface-active agents may be classified as anionic where the active portion of the molecule is an anion, cationic where the active portion of the molecule is a cation and nonionic where ionization does not take place. By far the greatest use of these materials is of the anionic type. Of the anionic compounds available, alkyl benzene sulfonate predominates in use. For convenience we shall refer to alkyl benzene sulfonate as ABS.

ABS is produced by polymerization of propylene derived from petroleum. It has the qualities desirable in a detergent, that is, relatively unaffected by hardness, effectively lowers surface and interfacial tension, wets, emulsifies and disperses soil and as a result is practically an ideal component of cleansing compounds. Certainly there are other surface-active agents reaching our water supplies but most of our attention has been directed towards ABS as the principal one encountered and an index to relative concentrations. In addition there is evidence that ABS is more resistant to degradation in waste treatment facilities and by natural processes in ground and surface waters.

In the formulation of synthetic detergents the packaged product may contain about one third or less actual surface-active agent, the remainder consisting of builders used to improve the cleansing properties or consumer appeal. Among the additives found in the final product are the following:

*Presented at the Annual Meeting, Mich. Section, AWWA, September 21, 1960.

Sodium tripolyphosphate
Sodium hexametaphosphate
Sodium phosphate, tribasic
Tetrasodium pyrophosphate
Sodium bicarbonate
Sodium carbonate
Sodium carboxymethylcellulose
Sodium metasilicate
Sodium silicate
Sodium chloride
Sodium sulfate
Scents, dyes and bleaches

It is interesting to note that because of the much lower percentage of synthetic surface-active agent in synthetic detergents as compared to soap as the surface-active agent in soap detergents, the net amount of actual surface-active agent being used has decreased even though the population has increased since their advent.

Analytical Determinations

No analytical methods for the determination of ABS are given in the tenth edition of Standard Methods.[1] However, at the time of this writing it has been announced the eleventh edition will include both infrared and methylene blue tentative procedures.[2] An American Water Works Association Task Group Report on analytical methods was published in the October 1958 Journal.[3] The report gives background information on the synthetic detergent problem and analytical methods for ABS. Both the methylene blue and infrared procedures are given in detail and are probably similar to the tentative procedures to be found in the eleventh edition of Standard Methods.

Infrared Method

This method is complex requiring considerable time, expensive equipment and skill. It is specific for anionic surface-active agents and most certainly is useful as a reference method and in research institutions. However, there is doubt that it will receive much use in routine water treatment plant analyses.

Methylene Blue Method

This method will measure ABS concentration plus the possible effect of certain interferences. If the test shows zero or relatively low (under 0.5 ppm) results, there is no particular need to resort to more complicated techniques. If a high result is found and the situation warrants the effort, the purification steps of the infrared method could be followed using a colorimetric (methylene blue) finish.[3]

Stated in simple terms the principal of this method is that methylene blue is soluble in water and not in chloroform. Chloroform is not soluble in water and being heavier than water will separate to form a layer even after thorough mixing. If ABS is present in a water sample, it will combine quantitatively with methylene blue to form a salt that is soluble in chloroform but not in water. In other words, the blue salt formed by methylene blue and ABS in a water sample can be extracted from the water-methylene blue solution with chloroform. An outline is presented below to illustrate the technique. No attempt is made to cover the details necessary for a workable method as this information will be in Standard Methods.

1. Select a simple volume based on estimated concentration of ABS. If less than 100 ml dilute to 100 ml with distilled water.
2. Acidify and transfer to separatory funnel.
3. Add 10 ml of chloroform and 25 ml methylene blue.
4. Rock vigorously for 30 seconds and allow chloroform to separate.
5. Draw off chloroform into second separatory funnel rinsing the delivery tube with chloroform. Repeat three more times.
6. Add 50 ml of wash solution to the second funnel. Shake, allow to separate and draw off chloroform through glass wool into a volumetric flask. Repeat twice adding 10 ml portions of chloroform to the separatory funnel containing the wash water. Rinse glass wool with chloroform.
7. Dilute to mark and make colorimetric comparison using properly calibrated spectrophotometer. Results are reported as ABS with the realization that this is apparent ABS and that the true value may be less than the apparent value obtained by the methylene blue procedure. Of course, if the methylene blue test is substituted for infrared measurement in the final step of the infrared procedure, the value obtained is quite reliable.

It should be noted in any of these procedures the final measurement must be made against a calibration based on known amounts of ABS. Measurements should not be referred to commercial products of unknown composition. Suitable material containing a known percentage of alkyl benzene sulfonate may be obtained from the Association of American Soap and Glycerine Producers, Inc., 295 Madison Avenue, New York 17, New York.

Effect On Water Supplies

Occurrence

First, let us consider the occurrence of ABS in water supplies. A great deal of evidence has been advanced in the literature on specific situations where ABS has been detected in both ground and surface waters. This is not surprising when one remembers that ABS unlike soap resists degradation by waste treatment facilities and by natural forces in rivers, lakes, and subsurface aquifers. In fact logic tells us that surface supplies subject to domestic waste discharges will contain ABS although in many instances dilution will lower the concentration below detection. In order to illustrate this, a series of samples from Michigan surface supplies was examined. Results are listed in Table 1.

Concentration of ABS, mg/l (Methylene Blue Procedure) in Certain Michigan Surface Waters

Table 1

Source	Sample Number 1	2	3	4
Clinton River, Utica	0.5	0.5	0.5	0.6
River Raisin, Blissfield	0.0	0.1	0.2	0.0
River Raisin, Dundee	0.1	0.0	0.1	0.0
Rouge River, Rockford	0.0	0.2	0.0	0.0
Cass River, Frankenmuth	0.0	0.0	0.1	

Samples were taken at approximately weekly intervals during August and September, 1960.

We have on record numerous laboratory reports of ABS concentrations ranging up to several mg/l in private wells. No instances of ABS contamination in municipal wells in Michigan have come to our attention. Municipal wells must meet certain enforced requirements of isolation and construction and are not commonly

in areas with numerous septic tanks and seepage beds. However, with time there is the possibility that ABS may be found in some of these wells.

A survey was conducted in a limited area with individual well and septic tank installations on small lots.[4] Well depths ranged from 12 to 30 feet.

Number of wells sampled	30
Positive for ABS	21
Positive for coliforms	5
Negative for coliforms and ABS	9

All the samples containing coliforms also contained ABS.

ABS occurrence in private wells, particularly in crowded areas, is more common because of the less effective controls on private wells and because private wells are usually associated with septic tanks discharging wastes including ABS which may eventually find its way to the water bearing formation. In another area, rapid housing development utilizing individual wells and septic tanks in a relatively shallow sand aquifer on an impermeable formation has led to numerous instances of ABS contamination. In one case flushing of a toilet resulted in sufficient foam to flow over the bowl onto the bathroom floor.[5]

To sum up, the occurrence of ABS in surface waters should not be a surprise if one first considers other uses being made of that body of water. One may readily predict whether or not samples are more likely to be negative or positive based on prior knowledge of the particular situation.

At present, if conditions are favorable, ABS may be found in ground waters. Depending on the specific sources of ABS and the type of water bearing formation, the length of time necessary before measurable quantities are detected may be a period from months to years or never.

Toxicity and Other Implications

The 1946 United States Public Health Service Drinking Water Standards do not include ABS restrictions. However, it has been proposed that a recommended limit of 0.5 mg/l be included in the next revision. It appears that aesthetic consideration was the prime factor in arriving at this limit when one considers that extensive research has shown that men can tolerate ABS at 100 mg/day for four months and that various animals have been fed diets containing from 0.1 to 1.0 per cent ABS for periods of months without ill effect.[6]

The lethal dose (LD_{50}) that will on the average kill fifty per cent of a group of animals has been reported to be in the range from 0.1 to 0.23 per cent of body weight for various animals. It the 0.1 per cent ratio is applied to a person weighing 100 pounds it would take one liter of 45,000 mg/l ABS to be lethal fifty per cent of the time. Based on present short term knowledge there is no reason to become alarmed from the toxicity standpoint about ABS levels being encountered in some water supplies. However, when one considers that sewage with an ABS content in the 10-20 mg/l range may be the source of the ABS, the public health signficance of ABS as an indicator takes on a different aspect.

In view of the lack of information on chronic effects of continually ingesting small quantities of ABS, our present concern about ABS is largely aesthetic. Frothing will usually occur in the 0.5 to 1.0 mg/l range but frothing is not always a specific indication of ABS.

Taste or odor may be present at any time but again is not specific as it reflects other substances that are associated with the mode of contamination.

Panel tests have shown that odor of purified ABS is rarely detectable below 1000 mg/l and that only sensitive individuals can taste it in water at concentrations as low as 16 mg/l.[7] Other investigators have reported that in 26 ABS contaminated wells, 10 per cent of the owners reported an off-taste at less than 1.0 mg/l while all those whose wells contained 1.5 mg/l or more reported an off taste.[8] Solutions containing from 0.0 to 3.0 mg/l of a standard household detergent were submitted to a panel of 23 members for taste tests. Less than half of the group detected taste at 1.75 mg/l or less. More than half reported taste at 2.0 mg/l and above. However, even at 3.0 mg/l, 9 out of the 23 people did not detect a taste.

Effect on Water Treatment

Research has shown synthetic detergents to have no serious effects on water treatment processes in the concentrations normally encountered[9, 10, 11]. Polyphosphates in some of the forms associated with synthetic detergents have been shown to interfere with coagulation in relatively low concentrations, requiring increased dosages of coagulant. However, in actual plant operation prior conversion of complex phosphates usually sodium tripolyphosphate to orthophosphate in sewage treatment and the counteraction by calcium and magnesium salts have minimized the effect. It should be noted that the orthophosphate may stimulate growth of algae leading to other treatment complications.

Removal of ABS

Removal of ABS in water treatment facilities does not appear to be practical.[9] Chlorine dioxide, aluminum sulfate, ferrous sulfate, settled sediment, precipitated calcium carbonate and clay have been investigated with limited success. Activated carbon is effective but only with high rates of application. For example it has been shown that to reduce 2.0 mg/l of ABS to 0.01 mg/l would require 154 mg/l of activated carbon. A reduction to 0.1 mg/l requires 76 mg/l carbon and reduction to 1.0 mg/l requires 10.5 mg/l carbon.

Removal of ABS in sewage treatment facilities shows promise.[12] Fifty per cent or more is removed in conventional secondary treatment. Removals in the order of 80 per cent may be accomplished in a high-solids, complete-mixing activated sludge system. The addition of a unit to induce frothing of activated sludge effluent with removal and separate disposal of the froth has given total removals from 82 to 93 per cent of ABS from an initial concentration of 10 mg/l ABS in the raw sewage.

Other solutions to the problem of ABS in water may result from research into alternate raw materials and processes for the production of suitable synthetic surface-active agents that do not resist biologic degradation.[13]

Summary and Conclusions

Synthetic detergents have been defined and differentiated from other detergents. The surface-active portion of synthetic detergents is reasonably represented by ABS for which analytical methods are available. The nature of ABS is such that it resists the usual degradation forces and per-

sists in our water supplies. There is no evidence of public health problems directly connected to ingestion of ABS but factual information on chronic effects is lacking. ABS is not amenable to removal in water treatment facilities except by relatively high applications of activated carbon. Efforts are being exerted to develop improved methods of removal in waste treatment facilities and alternate surface-active agents that readily succumb to biologic activity.

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Synthetic Detergents in Ground Waters — *Part 1*

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■ THE RISING use of synthetic detergents in this country during the past decade has introduced new problems in the water supply and sewage disposal fields. It is known, through the evidence of findings and the increasing publicity being given to the subject by Federal agencies, health authorities, research organizations, well-driller's associations and industry, that synthetic detergents (syndets) are not only capable of but are causing deleterious effects upon individual wellwater systems, public water systems, surface and ground water qualities, and sewage treatment plant operations. This discussion will deal with one phase of the problem: the effect upon individual well-water systems. The subject matter presented herein* does not necessarily reflect the official viewpoint of the Federal Housing Administration.

Discussion of Syndets

A knowledge of the nature and characteristics of syndets should prove helpful, before proceeding further on the subject. The use of syndets in this country has increased by about 700 per cent during the past decade. It is estimated that, at present, syndets represent about 72 per cent of the total market for cleansing agents of all types. Even a greater percentage can be anticipated with the application of syndets to bar soaps.

A syndet can be broadly classified as a chemical agent with cleansing qualities. Although soaps also fall into this general classification, there are important basic differences between the two. The syndet contains six major properties: solubility in water, wetting action, emulsifying action, stability in the presence of hardness, dispersing properties, and high resistance to biochemical degradation or breakdown. The syndet is about 25 per cent organic, while the soap is about 60 to 80 per cent organic. The soap is relatively unstable in the presence of hardness and acids, and has low resistance to biochemical degradation. Differences such as these have played a great part in the development and stimulation of syndets as a substitute for soaps.

The syndet is basically made up of two major constituents, known as surface-acting agents or surfactants and builder's agents. The builder's agents comprise about 67 per cent of the total. The surfactant is the active agent and combines the syndet properties mentioned before. The three types of surfactants are known as anionic, cationic and non-ionic, depending upon the degree of ionization developed and the nature of the electrical charge upon immersion into water. The anionic type is the most common by far, and represents about 72 per cent of the total. Because of its predominance in the field, the laboratory testing procedure for syndets consist in testing for anionic surfactants. The term "ABS", which one frequently hears, refers to the alkyl benzene-sulfonate group of the anionic surfactants. The cationic surfactant bears a positive charge as contrasted to the anionic type which bears a negative charge. The cationic surfactants has germicidal properties, is chiefly used as a sanitizing agent and is the most toxic of the three. However, the cationic type is rarely encountered in water, since it is neutralized by the more prevalent, oppositely charged anionic. The third type of surfactant is the non-ionic, which does not ionize appreciably in water and is usually non-sudsing. The non-ionic is on the rise in the market, and is most commonly used after the anionic type.

*Based on a talk presented before the 1960 Home Sewage and Waste Disposal Conference, Michigan State University, East Lansing, Michigan.

The builder's agents comprise about 67 per cent of syndets and are inserted to further improve the basic detergent properties. They consist of chemical compounds such as phosphates, silicates, etc. Since the advent of syndets on the market, it is stated that the phosphorous content of domestic sewage has at least doubled.

Analytically, the laboratory test for syndets consists of reacting the anionic surfactant with methylene blue dye, the latter being a colored cation, with formation of a blue salt. Chloroform is then used to extract only that portion of the methylene blue which has combined with the anionic surfactant, which is the blue salt, and the intensity of color produced is measured photometrically or by means of a commercially available syndet color comparator. The photometric determination uses a calibrated anionic surfactant chart for comparison purposes. Since the concentration of the anionic surfactant varies directly with the color produced in this determination, as the syndet concentration increases the color increases.

The Suffolk County, L. I., Problem

Description of Long Island

Long Island, N. Y., includes the four counties of Kings, Queens, Nassau and Suffolk. Kings and Queens are part of the city of New York, have a little over four million people between them, and are practically fully served by public water and sewerage facilities. Nassau County, lying to the east of the Queens border, has a population of about 1.5 million and is almost fully developed. Nassau County is virtually fully

served by public or publicly controlled centralized water systems, with only a small percentage of public sewerage facilities. However, a master sewerage system was started a few years ago. The extreme western part is now sewered and progress is continuing on this plan. Because of the extremely porous subsoil in Nassau County, the vast numbers of individual sewage disposal systems in use are giving good service, but they have caused some pollution of the relatively few individual well-water systems still in use. Little data is available as to the possible pollution by syndets of the public water systems all of which use central wells.

Suffolk County is the most easterly of the four counties but covers about two-thirds of the Island in area. Although the population of Suffolk County is the lowest of the four counties (0.7 million), it is the most rapidly developing, and has a high population potential. Suffolk County is less than 5 per cent publicly sewered, with most of these serving business areas. The dual cesspool type of individual sewage disposal system is commonly used, and service has been good because of the highly permeable subsoil. Unfortunately, however, the high permeability of the subsoil has contributed in part to syndet and sewage pollution of the individual wells.

About one-third of the population of Suffolk County is served by individual well-water systems, which are normally driven into the highly permeable sand and gravel strata underlying most of the County. It is estimated there are about 50,000 such wells. There are about 90 public or privately owned centralized water systems, but these facilities are so scattered and varied in size as to leave many areas without service. The rapid development of the county has furthermore placed these central water systems out of reach in many areas.

Geology of Suffolk County

The County contains three water-bearing strata which for all practical purposes can be considered as separate hydrologic units. The Glacial Stratum underlies most of the Island and is the closest to the surface. It is composed mostly of highly permeable sand and gravel deposits interspersed occasionally with small clay layers. The Glacial Stratum is a highly productive water-bearing formation, its water table is relatively close to the surface, and it is therefore almost exclusively tapped as a source of water supply. Unfortunately, the use of this upper stratum as a source of disposal of sewage effluent from the commonly used individual sewage disposal systems, makes the continued use of this stratum questionable since it is becoming increasingly polluted.

The Magothy Stratum underlies the Glacial Stratum, and is much less permeable, being chiefly composed of fine clayey sands and silts. Because of its depth, wells of over 100 feet would be necessary, but it probably contains a reasonably good, though limited, source of water. It is virtually untapped. The third, and deepest stratum, is the Lloyds Sand, composed chiefly of sands, gravels and some clays. It is artesian in nature, being separated from the overlying Magothy Stratum by an impermeable stratum called Raritan Clay.

Discovery of the Syndet Problem

During 1955, the County Health Department was investigating individual well-water complaints from a small community in the southwestern part of the county. The residents complained about unusual tastes, odors and color in the well-water supplies. It was finally revealed by the Health Department that the source of the complaints was from hexavalent chromium waste discharged from a metals finishing plant located near the community.

Wastes were being discharged into large underground disposal pits, with the seepage from the pits entering and polluting the ground water as it flowed towards the community. Laboratory analyses revealed that the well-water samples carried as much as 10.8 ppm of hexavalent chromium. The U. S. Public Health Service Standards recommend a maximum safe concentration of only 0.05 ppm. It was also found that the chemical waste had traveled over 1,000 feet from the source, was still affecting wells two years after the plant was shut down, and was highly objectionable to the consumers of the affected well-waters. Residents purchased bottled water for as high as $0.17 per quart.

While the investigation was being made of the hexavalent chromium waste, it was further discovered that there were also syndets in the well-water supplies. The physical characteristics of the community included 300 houses on typically sized 60′ x 100′ lots, driven wells varying in depth from 14′ to 56′, water table at about 7′ to 12′, and a porous, deep layer of sand and gravel subsoil. The origin of the syndets was from the individual sewage disposal systems. A chemical breakdown of typical polluted waters revealed that abnormal concentrations of chemicals normally associated with sewage, such as nitrates and chlorides, plus high oxygen consumed tests, were found. The syndet, found in one-third of the wells tested, ranged from a trace to 1.4 ppm. There were complaints of foaming, tastes and odors in various degrees.

Action Taken by the FHA in 1957-1958

Cooperation between the Suffolk County Health Department and the Federal Housing Administration sanitary engineer serving the local FHA field office in Jamaica, New York, has been close and constant, in a common effort to find ways and means to control and solve the problem. It is emphasized that the FHA field office's policies and procedures regarding the matter have been under the continuous guidance and consultation of its sanitary engineer.

The FHA field office immediately set up a policy to refuse all applications in the syndet-polluted area for mortgage-insurance purposes. This policy became effective in late 1957. The FHA sanitary engineer realized that the problem was probably more widespread than the immediate health department survey indicated. Because of a similarity in subsoil and ground water conditions, plus other physical factors involved, the sanitary engineer advised the FHA field office to cease accepting lots in similar surrounding areas with individual wells and sewage disposal systems. Furthermore, the FHA field office suspended accepting subdivisions in the county where both individual wells and sewage disposal systems on the same lot were proposed. It awaited further information on the problem.

The Federal Housing Administra-

tion objectives for an acceptable water supply include requirements for a potable, palatable, and continuing supply. Although it was not proven the syndet pollution was unsafe, it was proven to cause adverse effects upon the palatability of the water supplies, and because of its sewage origin could be suspected as indicating a possibly unsafe water.

In August, 1958, the FHA field office issued a public circular which set forth new requirements for acceptability of lots containing both individual well-water supplies and sewage disposal systems, and these requirements were limited only to non-subdivision lots where public water was deemed infeasible. They included:

1. Wells must be driven at least 40 ft below the ground water table, with the minimum overall acceptable depth being 50 ft.
2. A minimum depth of 20 ft of watertight casing must be provided.
3. Minimum separating distance between wells and disposal systems must be 100 ft for all types of sewage disposal systems.
4. All constructed wells must be certified to by a licensed well-driller as to compliance with these new requirements and all other pertinent FHA outstanding requirements.

At about the same time the FHA issued these new requirements for individual wells and sewage disposal systems on the same lot, the Suffolk County Health Department issued a Resolution to the ten towns of the County setting forth new County Health Department requirements on the same subject. The County Health Department's new requirements:

1. Concurred with the new FHA minimum well depths.
2. Increased the minimum separating distance between well and sewage disposal system from 65′ to 100′, with one concession. Where the new 100′ distance was impossible to attain, it permitted reduction of the distance to no less than 65′, provided that the well was driven to a greater depth than the new minimum of 40 ft below the water table, in a manner proportionate to the amount of decreased permissible horizontal separating distance.
3. Towns were required to submit substantial evidence that constructive means were being taken to make public water more accessible.
4. A ¾″ copper service line was to be installed at the time of the individual well installation, for future public water connection.
5. Subdivisions with both individual wells and individual sewage disposal systems would be considered only after it has been determined that feasibility of public water is not evident, that the new minimum well depth and separating distances to the sewage disposal systems are complied with, and that the maximum plot density does not exceed two houses per acre.

New Policy Established by FHA in 1959

Further studies of the syndet problem by the County Health Department, with continued cooperation and consultation by the FHA Sanitary Engineer, confirmed that the problem was definitely widespread and not confined to the high-density, high-water table areas in the southwestern part of the county. Evidences of syndet pollution were picked up in areas further to the east, in areas with plot sizes up to ½ acre, and water tables up to 40 ft. This was not surprising, since previous studies had revealed the stability of the syndets, their ability to travel long distances both vertically and horizontally, and the typical subsoil conditions found in these syndet-polluted areas.

After a series of conferences with the Health Department, builders and well-drillers, the FHA field office issued a new set of requirements pertaining to acceptability of lots with both individual wells and individual sewage disposal systems. The purpose of these new requirements were to (1) provide a greater measure of safety to the wells regarding potability and palatability features, (2) curtail or preclude FHA participation in slowly developing areas being built up by numerous small builders, with the end result involving high-density subdivision-type situations, (3) preclude any FHA participation in areas that have a history of or have a potential for syndet-polluted, and possibly bacterial contaminated, drinking water supplies.

The new FHA requirements were issued by a public circular in April, 1959, and the following basic stipulations were specified:

1. Pertained only to individual, scattered lots. No subdivisions or developing areas with lots containing both individual wells and sewage disposal systems were considered for mortgage insurance purposes.
2. Individual wells would not be considered in any areas where the depth of the water table in the upper Glacial Stratum was less than 40 ft below ground surface.
3. The well must now be driven at least 40 ft below the minimum permissible water table depth of 40 ft. This would therefore require a minimum overall well depth of 80 ft.
4. Minimum allowable lot size would be 20,000 square ft. This was to allow the home owner to relocate his well or sewage disposal system if necessary, without endangering his neighbor's well supply, or his own. Furthermore, if slow, piecemeal development of some areas with individual sewage systems occurred, and this was not preventable in all cases, then the areas in which the FHA could be involved would be restricted only to low-density, deep-well areas. Also, the larger lot size would give the builder some means to locate the well system reasonably away from the path of sewage discharge from on lot, or from adjacent individual sewage disposal systems.
5. All wells showing evidence of syndets would be rejected. This affected particularly existing lots with well-water systems.
6. Minimum separating distances between well and sewage disposal system were maintained. Well-driller's certification of "as-constructed-well" was maintained as a requirement, as were casing details.
7. All highly built-up areas, where individual wells and individual sewage systems were involved on an existing or proposed construction basis were ruled out for further consideration
8. Before wells and individual sewage systems on the same lot

would be considered, the applicant was required to furnish an economic feasibility report concerning location of nearest public water main and possibility of connection, as compared to cost of the individual well system.

Investigation of Problem by the Builders

In June, 1959, the Long Island Home Builder's Institute contracted the services of the largest well drilling organization on the Island to further study the problem. In a rather limited study, but one receiving the cooperation of the FHA sanitary engineer and Health Department, it was found that a very light evidence of syndet-pollution was encountered in subdivision areas up to ½-acre plot sizes, in subdivisions less than 3 years old, and water table areas up to 44 ft depth. It indicated that although there is evidence of syndets finding their way into light-density areas with deep water table, these factors of light plot density and deep water table cut down on the problem and probably are factors of relative safety. However, these factors only appear to be time-saving devices, and are not a solution to the syndet pollution of the ground waters.

Summary of Imposed FHA Requirements

The established FHA field office standards with relation to acceptability of individual well-water and sewage disposal systems on the same lot are stricter than those presently in force by the Suffolk County Health Department. Since late 1957, the FHA field office has not accepted subdivisions with such facilities. It ceased insuring proposed and existing houses in highly built-up areas in early 1959. It has set up new minimum well-depth criteria based upon factual data received to date which indicates that wells of lesser depth, and in shallower water table areas have or probably will become syndet-polluted. Minimum lot sizes have been established as another criterion for acceptance based upon the plot-density being a factor for impossible well pollution.

The County Health Department, which has greatly strengthened its requirements regarding individual well systems and sewage disposal systems on the same lot imposes lesser restrictions than the FHA office at this time apparently based on the probability that it is close at hand and may increase its restrictions if rapid deterioration of ground water occurs. The Federal Housing Administration, on the other hand, considers a water supply on the basis of palatability in addition to other adversities. It is known that syndets cause taste, odor and aesthetic problems when reaching certain concentrations, said to be in the range 1.0-1.5 ppm. Considering the long-term aspects of FHA requirements governing acceptability of properties for mortgage-insurance purposes, the affect of palatability upon water supplies which the syndets are known to cause, the origin of syndets from sewage disposal, and the tendency for syndets to build up in a ground water over a period of time, this author believes that the FHA field office requirements are justified and realistic.

FHA and Health Department Control Measures

It is encouraging to note that since the imposition of the FHA and Health Department control measures, progress is being made to solve County ground water supply problems. The Suffolk County Water Authority, which is a Public Benefit Corporation and largest supplier of water in the County, has liberalized its public water expansion policies. The Suffolk County Water Authority has increased the allowance per customer for free water main extension, from 50 to 70 ft. This represents about a $100 savings per home owner. The Authority has adopted a surcharge plan designed to permit customers to repay the cost of water extension over a long period of time. The Suffolk County Water Authority and the Suffolk County Board of Supervisors are examining the feasibility of legislative and financial adjustments aimed at liberalizing present water main expansion policies.

New legislation was passed in March, 1959, to modify existing town laws to more readily permit formation of water districts. Water committees and civic associations have been formed to explore the water supply problem and to find ways to more easily provide public water. There has been talk about planning a master sewerage plan for the County. There has been more interest expressed by builders to provide central water supply systems, and some have submitted plans. There has been a radio address to the County residents by its Congressional Representative, advising them of the water supply problem with relation to syndets, and the need for a fresh constructive approach to the problem.

Synthetic Detergents in Ground Waters—*Part 2*

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Latest Moves by the County Health Department

In October, 1959, the County Health Department increased its restrictions on maximum plot densities for subdivisions with both individual water and sewage disposal systems on the same lot. It now requires a minimum lot size of 20,000 sq ft, in lieu of its former requirement for maximum plot density of two houses per acre. Under the latter requirement, lots of less than 20,000 sq ft could still qualify since the plot density basis included streets, parks, etc. The Health Department minimum lot size requirement for subdivisions now checks with the FHA field office requirement, although the FHA field office only accepts such lots on an individual, non-subdivision basis. The Health Department has also indicated that they are going to increase the minimum separating distance between individual well and sewage disposal system to 100 ft in all cases, without exceptions. The increase in minimum separating distances will then check with the minimum FHA field office requirements. (However, it should be mentioned that the FHA field office has increased its minimum separating distance between individual well and double-cesspool system to 150 ft).

A Typical Case Involving Syndet Pollution

Finally, it may be of interest to illustrate a case history on record in the County involving syndet pollution. A tenant complained of severe sewage odors, tastes, and foaming of the water supply at the tap, and finally moved out of the house because of concern for her child. The individual well supplying the house was 32 ft deep, and it was located 27 ft from the cesspool on the property. Analysis of the water revealed a syndet concentration of 4.8 ppm.

To correct the situation, the property owner deepened the well from 32 ft to 46 ft. However, syndets in greater amounts were found, at 5.3 ppm concentration. The well was then deepened to 65 ft, and the cesspool relocated from its original distance of 27 ft, to a new distance of 75 ft. Syndets were found to still be high, since tests revealed a concentration of 3.8 ppm. The well was then deepened, further, from 65 ft to a new depth of 76 ft. However, syndets were found at even a higher concentration of 4.9 ppm.

Lastly, the owner reduced the well depth back to 34 ft, with the cesspool remaining at the increased distance from the original 27 ft, to the new 75 ft distance, and the syndets were found at the lowest concentration, with tests revealing only 0.5 ppm.

In this particular case, the increased separating distance between the well and the individual sewage disposal system proved to be the relieving factor, with the increase in well depth actually worsening the problem. It is significant to note, that if the owner did not have sufficient room to relocate the sewage disposal system, a solution could not have been reached. Although the solution reached relieved the problem at the time, it can only be considered as temporary in nature, since syndets have shown a breakthrough even at the altered locations, although light in nature at the time. The case does illustrate, however, the need for sufficient lot space to provide at least temporary relief.

Unfortunately, increasing the separating distance is not always the answer, since well deepening in other cases may be necessary.

Upon receipt of information from the FHA field office in Providence, Rhode Island, and from the Rhode Island State Department of Health, the FHA sanitary engineer investigated the problem of syndet pollution in the town of Portsmouth, Rhode Island.

A 50-house development, built up slowly, and over a period of several years, was located in the town of Portsmouth, Rhode Island, in the County of Newport. Lots were typically sized from 7,000 sq ft to 12,000 sq ft, and served by individual drilled wells ranging in depth from 100 ft to 300 ft. Each lot was also served by individual sewage disposal systems of the septic tank and disposal field type, and located from 30 to 150 ft from the well systems, with an average of 75 ft.

Geology

Subsurface soil conditions included a thin mantle of glacial till composed of fairly impermeable sandy-clay, with shaley, carboniferous rock at about 10 ft depth. Ground water levels were usually at 10-15 ft depth, but fluctuated widely on a seasonal basis. The water-bearing character of the underlying rock was poor, a characteristic which is prevalent throughout the County.

Discovery of the Syndet Problem

Actually, the syndet pollution of individual wells in this development had been occurring since 1957 or possibly before, but complaints from the residents brought about a detailed investigation by the State Health Department in early 1959. The State Health Department tested half of the wells (25) and found that all but one had syndet pollution, ranging from 0.15 to 5.0 ppm. The well with the highest concentration of syndets was 250 ft deep. Nitrates were found in high con-

*Based on a talk presented before the 1960 Home Sewage and Waste Disposal Conference, Michigan State University, East Lansing, Michigan.

centrations, ranging up to 20 ppm. Six of the wells were also found to be bacteriologically contaminated. This included the one well showing no apparent evidence of syndet pollution.

Including these data in a report dated June 17-18, 1959, the Rhode Island State Department of Health reported as follows:

1. Seventy-two well waters in various parts of the State have shown evidences of syndet pollution. 56 per cent of the wells showed bacterial contamination. One-fifth of the wells were driven and one-third were drilled. 73 per cent of the wells were within 50 ft of the sewage disposal unit, and 94 per cent were within 100 ft. More than half were tested because of taste, odor, and foaming complaints with the majority of complaints being tastes and odors.
2. Syndets are very stable, travel appreciable distances through the ground and into the water table and move with the water table. (This confirmed the Long Island findings).
3. Foaming will generally appear at 0.5 to 0.6 ppm.
4. Wells are considered to be polluted or a pollution potential exists because of the presence of syndets.

Findings by FHA Sanitary Engineer

In December, 1959, the FHA Sanitary Engineer visited the site and picked up samples of water from the taps of 13 houses scattered throughout the area. Six of the samples foamed upon shaking the sample, indicating rather high concentrations of syndets. Odors were light, but where perceived, exhibited perfumey, fish-like odors. In some cases, the water foamed considerably at the tap.

A temporary steel water tank had been put in one of the streets to provide emergency water supply from other sources. The fire department maintained it, but it was grossly inadequate for the purpose. Many residents were purchasing bottled water from a street vendor at $0.85 per gallon. A number of home owners had put their houses on the market but could find no buyers. The FHA field office would not accept houses in the development for mortgage insurance purposes.

A conference at the State Health Department between the FHA Sanitary Engineer, the State Chemist who conducted the survey, and Health Department Engineers, revealed that since the Health Department's detailed investigation and report of June, 1959, additional wells in the development showed evidence of syndet-pollution, and that additional wells showed bacterial contamination. The Health Department considered wells with syndet pollution as being potentially unsafe, and so advised the residents upon their inquiry.

Corrective Measures by Town of Portsmouth

In August, 1959, the Town of Portsmouth set up new provisions governing the acceptability of both individual wells and sewage disposal systems on the same lot. The Town increased the minimum permissible lot size to 20,000 sq ft, increased the minimum separating distance between well and sewage disposal system to 100 ft, and issued special, detailed well casing requirements to be imposed under Town supervision.

In November, 1959, the Town of Portsmouth applied to the FHA "Community Facilities Administration" for funds to be used for the planning of a public water supply system for the entire town, including this affected development. The estimated cost of the water system was $1,600,000. The Town, at present, has two very small community water systems, in opposite parts of the town, and extension of such facilities to the affected development is excluded because of the 2 to 3 miles distance involved. No immediate relief for the development is foreseen.

Rhode Island State Department of Health Requirements

The Rhode Island State Department of Health subdivision recommendations of 1957 state that where individual well-water systems and individual sewage disposal systems on the same lot are proposed, that:

1. Where drilled wells and septic tank absorption field systems are proposed, the minimum sized lot should be at least 2 acres.
2. Where drilled wells and septic tanks and seepage pits are proposed, the minimum sized lot should be at least 3 acres.
3. The minimum separating distance from any well to any sewage disposal system should be at least 100 ft.

Since the FHA field office requires State Department of Health approval of all subdivisions, it has therefore, not accepted any Rhode Island subdivisions with both individual wells and sewage disposal systems since 1957.

FHA Control Measures Regarding Acceptability of Wells

Based upon the syndet problems mentioned by the State Health Department and evidence that it is a general State-wide problem, the FHA field office set up in December, 1959, a new set of requirements based on its sanitary engineer's advice. They are:

1. No subdivisions with wells and individual sewage disposal systems would be accepted unless compliance with the minimum State Health Department restrictive lot sizes is provided. (This virtually ruled out subdivisions).
2. Only those lots in remote, rural type areas would be considered. Any lots which had been located in a subdivision previously rejected under paragraph 1 above, or in an area subject to high-density build-up would be rejected even though being applied for on a non-subdivision, piecemeal basis. This would prevent subterfuging of FHA basic policy on the subject.
3. Individual lot size must be 20,000 square feet.
4. All well construction must be certified to by a licensed well-driller.
5. Each well application, where an individual sewage disposal on the same lot was proposed or exists must be studied individually as to distance of nearest public water main, feasibility of extension, etc.
6. A proposed well or existing well which shows evidence of syndets would be unacceptable.

Other Information Pertaining to the Syndet Problem

Johnson National Well Drillers Journal, November-December 1959

Page 3 of this Journal says the acceptability of a water-bearing stratum in limestone or similar creviced or fractured formations should be dependent upon the existence of at least 40 ft of overburden of unconsolidated materials which extends ½ mile in all directions from the well site. The well must also be sealed into the rock. (This 40 ft recommendation coincided with the 40 ft protective layer required by the FHA field office in Jamaica, New York, where individual wells are proposed to be driven through the usual sand and gravel formations overlying the water table). The Journal, however, made no mention with respect to this 40 ft recommendation as to the protection afforded, if any, against possible syndet pollution.

The Johnson Journal points out on page 5 that tests made in California (re: "Report on the Investigation of Travel of Pollution", State of California Pub. #11, 1954) revealed that pollution travels farthest and most rapidly in the direction of ground water flow and that chemical pollutants travel much farther through sand than do bacterial pollutants. It also revealed that coliform bacteria were found up to 100 ft from injection wells, with diminishment of concentration upon greater distance from the source of pollution. The article states, however, that the injected polluted water used in the tests contained little or no syndets and that it is unknown whether detergents would have helped bacterial pollutions to move greater distances from the injection well.

Also on page 5 the Journal states that detergents used for dishwashing, cleaning, and laundering are chemical contaminants and that sewage digestion and percolation through the ground water remove only part of the detergents from waste water. It states that it appears that once the detergent reaches the ground water reservoir, that it will continue unchanged for quite a long time.

On page 6 mention is made of the contamination of water-bearing strata which has been discovered in the suburban developments around St. Paul and Minneapolis, Minnesota. The source is from sewage seepage into the ground waters, originating from cesspools, septic tanks and drain fields. The Journal states that the Minnesota Health Department has tested the well-water supplies and found syndets and higher-than-normal nitrates in 31 to 83 per cent of the samples tested. Although, it is stated, the chemical evidence of pollution has been found more often than bacterial pollution, it is clear that sewage is recirculating back into the drinking water supplies and this is a warning flag.

New York State Health Department, Dutchess County Health Department

Discussions with engineers from these health authorities have revealed an increased interest in the syndet problem. In the Dutchess County, New York area, a development with individual wells drilled into a stratum of limestone was found to contain syndets and some bacterial pollution. To the north of Albany, New York, it is reported that in a section encompassing some 300 homes 24 of 26 tested individual wells showed the presence of syndets. This latter area contained a porous sand and gravelly subsoil with ground water within 20 ft of grade. Both of the above areas were of course served by individual sewage disposal systems. The State Department of Health has indicated active plans to study the problem.

U. S. Geological Survey, Water Resources Division, Department of Interior

This Agency conducted a preliminary reconnaissance study of the role of anionic surfactants in ground water for the Federal Housing Administration in May, 1959. Areas in six states in the Midwestern, Southern and Western states were checked, and evidences of syndet pollution were encountered to varying degrees. Among the findings tentatively advanced were that nitrates were found in many cases along with the syndets. Significant factors related to the syndet pollution problem include the effect of separating distance between well and sewage disposal system, depth of well, direction of ground water flow, concentration of syndets discharged into the area, etc. Further studies are continuing.

United States Public Health Service

The October 1959 edition of the Journal of the American Water Works Association states that the U.S.PHS is studying the ground water contamination problem. In a New York newspaper, dated December 29, 1959, a representative of the Division of Water Supply and Pollution Control, U.S.PHS, reportedly stated that our drinking water is being polluted by hundreds of new chemicals whose affect on human health are totally unknown. Detergents are reported among these chemicals.

Journal of American Water Works Association, October 1959 Edition

An article was published entitled "Effects of Syndets on Water Supplies, Task Group Report," and discusses the high resistance to biochemical degradation of ABS and other surfactants. It is stated that detergent manufacturers are studying the possible use of a material in syndets less resistant to biochemical action without reduction in the basic syndet qualities. A change to a less resistant substitute will not be easy, however, since ABS is produced on a scale reported in 1956 to be at least 455 million pounds.

Summary of Findings and Conclusions

From the information discussed herein, some of the findings and conclusions can be summarized as follows:

Syndets represent a growing problem relative to the palatability of ground water supplies. There is little, if any, significant data available relating to the toxicity of syndets and studies are under way on this matter.

Where syndets are found in individual well systems on lots also served by individual sewage disposal systems, experience has indicated that frequently the chemical analysis of the water supply also reveals abnormal concentrations of chemicals usually associated with sewage. The syndet therefore acts as an effective tracer for the confirmation of sewage seepage into ground water. In some areas it has been found that after the initial presence of syndets, bacterial pollution enters the picture in increasing amounts.

The syndet is highly resistant to biochemical degradation, in contrast

to soaps which are much less resistant and of higher organic nature. This high resistance of syndets plays a major factor in the high buildup of syndets in a syndet-polluted ground water. Retesting of syndet-polluted water supplies has shown in many instances that the syndet concentration increases with time.

Evidences of syndet pollution have been found in various types of subsoils, ranging from fractured rock to sands and gravels. In Long Island, they have been encountered in water wells with water tables to 44 ft depths and sand and gravel soils. In Rhode Island and Dutchess County, New York, syndet has been found in limestone and shalely rock formations. Other evidences of syndet pollution have been found in many parts of the country.

The syndet, like many other chemical pollutants can travel extensively both horizontally and vertically without being broken down. They have been traced at least 95 ft deep and 1,000 ft horizontally from the source.

Direction of ground water flow is significant in the possibility of syndet pollution, since syndets travel much more rapidly once they enter the ground water. However, in large housing developments having limited lot space available it is usually impossible to locate wells such that septic tank effluent does not discharge into the ground water en route to the well. The provision of a deep soil barrier above the ground water should provide reasonably good protection against bacterial pollution, but is only a time-delay against the eventual pollution by syndets as far as experience to date reveals. In Long Island a 40 ft soil barrier is required as a minimum by the FHA field office, but this is based upon lack of evidence of significant syndet pollution at that depth to date.

As suggested by some authorities, the existence of an impermeable soil barrier above the water bearing stratum and below the point of individual sewage disposal discharge should be reasonably effective against bacterial and syndet pollution. However, the necessity for proper casing and sealing of this casing into the impermeable stratum requires unusual supervision of well-drilling operations and skilled installation. It also requires a good knowledge of the extent and character of the impermeable stratum. Unfortunately, licensing of well-drillers, adequate supervision by health, local municipal, and Federal authorities is limited and difficult to obtain.

Plot density is an important factor in controlling the effects of syndet and/or bacterial pollution. It is important to decrease the syndet concentration, give the home owner recourse to relocation of his well or individual sewage disposal system in case of pollution from his own sewage system or his neighbor's, and to obtain maximum protective separating distances.

Syndets have been found to cause foaming, tastes and odors in well-water supplies at concentrations from 1.0 to 1.5 ppm and higher. The simple "shake test" of suspect samples can reveal foaming characteristics and can prove of some value in general surveys of the problem.

The FHA field offices in Jamaica, New York, and Providence, Rhode Island, have taken very definite steps to meet the problem. Residential developments involving both individual sewage disposal systems and wells on the same lots are not acceptable, and community water supply systems or extension to public water systems are required for FHA mortgage insurance purposes in those areas. Individual lot applications in non-development areas are considered but only under specified requirements which evidence has indicated will provide maximum protection to the wells from both a bacterial and chemical viewpoint. The evidence of syndets is considered as indicating an unacceptable well-water supply. Other Federal Housing Administration Insuring Offices in the New York-New England area have virtually ceased consideration of developments with both individual wells and sewage disposal systems and have greatly limited further consideration of non-development lots with such facilities.

The cooperation of the Health Authorities is essential, and my experience has definitely indicated that where this cooperation is obtained, the combined efforts of the FHA and Health Authority has produced successful results in the installation of public and community water supply facilities to serve the homeowners. Because of long-term factors and others which involve considerations in addition to public health protection, FHA field offices in the New York-New England area have imposed restrictions on lots involving wells and individual sewage disposal systems which are far greater than those of the Health Authorities. An immediate, aggressive, constructive and direct approach by the Health Authorities, Federal and local agencies is needed now more than ever before to provide the maximum protection to the ground water supplies and to the nation's ground water resources.

A report of the latest research work investigating the effects of . . .

Household Detergents in Water and Sewage

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EDITOR'S NOTE: There is probably no other material that in recent years has been the subject of as much research and discussion as synthetic detergents. Much of this research work has been sponsored by the Association of American Soap & Glycerine Producers who have now or have had projects at many universities where sanitary engineering is taught. In this paper, originally presented at the 7th Ontario Industrial Waste Conference (Honey Harbour) and published with permission, the author reviews the highlights of the research work now in progress. This work has ranged from studies of the phosphorous content of an Illinois river to the bacterial degradation of alkyl benzene sulfonate. Of special interest is the work on foaming.

■ BY DEFINITION, A DETERGENT is anything that cleanses. As such, ordinary soaps, the new "synthetic" detergents, plain water, even sand when used for scrubbing, can all be classified as detergents. What really is of interest, however, are the synthetic detergents which have become so popular since World War II, and how these relatively new materials compare with the soap products which the housewife has used for years. The following simplified comparison between the two types of product may help to point up the similarities between the two, and make them both more understandable.

In Fig 1, which shows a representation of the two major types of packaged household washing products which the housewife might purChase, both the "synthetic" and the "soap" products are labelled as "detergents". Definite points of similarity exist between the two, in that the large proportion of each contains a surface active agent and a phosphate builder. The surface active agents, or surfactants as they are also called, differ between the two, as does the exact chemical identity of the phosphates. Also, the amounts or per cents of each are obviously different. Nevertheless, in the broad sense they both contain the same basic types of materials which, when properly formulated, combine to get out the dirt.

The next concept is very important to understand, because a misunderstanding frequently leads to misleading reporting of results. After a packaged product, either soap or synthetic detergent, is used for laundering, and released down the drain, it loses its individual brand identity, and must be considered on the basis of the individual components; i.e., the "surfactant" portion and the "builder" portion. Different manufacturers market different formulations in terms of per cent of individual components, but the chemical nature of the components themselves may be the same. Thus, once in water or sewage, only the components can be considered.

This is logical from the viewpoint of practical effect, too. For example, as will be brought out later, it is the surfactant portion of synthetic detergents which has been associated with frothing, not the phosphate builder portion. And the phosphates have been associated with algae growth, not the surfactants. Thus, they should always be considered separately.

In line with this, it is important that the components be named correctly, and it would be well to go on with the comparison of the packaged soap and synthetic detergents in order to make certain the terminology is completely understood.

The surfactant portion of either product is an organic agent which at laundering concentration lowers surface tension and penetrates between the soil particles and the cloth, thus helping to remove the soil when the fabric is agitated in the washing machine. It also is the material which makes the suds.

In the soap detergent the surfactant portion is called by the same name—soap, a name applied to it for many centuries before chemists finally identified its specific chemical structure. To be technical, it is the sodium or potassium salt of a fatty acid derived from a natural fat or

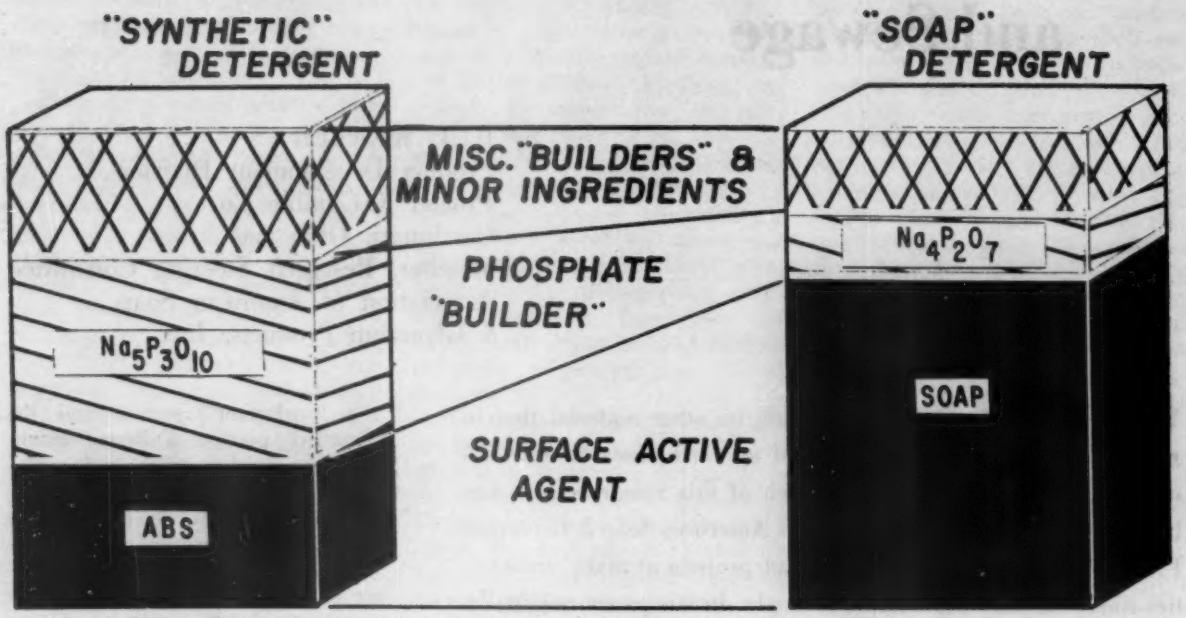

Fig 1 A REPRESENTATION of the two major types of packaged household washing products

oil. In the soap detergent this surfactant material may be as much as 90 per cent of the formulation. Thus, there isn't a great deal of difference in terms of per cent between the surfactant portion and the entire package soap product, and calling this surfactant "soap" does not lead to serious confusion.

In the synthetic detergent, however, as Fig 1 shows the surfactant portion is a much smaller per cent of the entire product than in the case of the packaged soap detergent. In this case to call this surfactant portion by the same name as the entire packaged product; i.e., "detergent" can lead to real confusion. This is a problem which has shown up many times in the literature, where persons may say detergent but actually mean surfactant, with the result that the interpretation of the reported findings is in error.

For clarity, therefore, it is strongly recommended that the terms "synthetic detergent", "detergent" or "syndet" be reserved for the complete packaged product; and the term "surfactant" or "surface active agent" be used for the organic sudsing agent. When this is done, the problem is automatically straightened out, and the reporting and interpreting of data are clarified. The specific surfactant material most widely used in household synthetic detergents, and which has been the subject of most of the U. S. research, is known as ABS, alkyl benzene sulfonate.

The phosphate builders present in both packaged household soap and synthetic detergents are mildly alkaline complex phosphates which, because of their soil suspending and hardness sequestering properties, help "build" the formulation into a product which will do the best job of getting dirt out of clothes. The specific phosphate compounds used in the packaged synthetic and soap detergents are not very different.

One interesting point which might be mentioned in passing is that in the U.S. the combined per capita consumption of packaged detergents and soaps has remained about the same during the years when detergents replaced soaps in the home. Total consumption, of course, has increased as the population increased. Actually, less surfactant from synthetic detergents enters the sewers today than did the surfactant "soap" thirteen years ago, because there is so much less surfactant in packaged detergents.

Analytical Aspects

Another point which merits a brief discussion deals with the analytical aspects of the detergent question. There are several methods available for the determination of ABS in water and sewage. The most widely used is the methylene blue colorimetric procedure, which was published in the October 1958 JAWWA[1] by the AWWA Task Group on Analytical Methods for ABS. However, as the Task Group cautions in its report, this method is subject to interferences, and at times can give misleading results. The Task Group therefore recommends that questionable results be checked by the referee procedure developed by the Soap Association[2] which is also included in the Task Group report. This method, based on infrared principles, is long, and consequently not normally used for routine checking. It definitely should be used if there is any question about results, however. Both of these methods recommended by the AWWA Task Group are expected to appear in the next issue of Standard Methods.

Improved methods for phosphates are also now available. A procedure developed by a Soap Association com-

mittee was published in the December 1958 issue of the JAWWA[3].

Algae Problems

The first of the two Canadian problems to be discussed is the question of algae growth. It is well known that some hold the opinion that phosphates derived from detergents have caused a significant increase in algal blooms. As it happens, the Soap Association has not sponsored any research on this particular problem, and thus it can only be discussed on the basis of what can be learned from the literature, and from talking with experts in the field. However, if nothing else, this review has established the fact that a good deal still needs to be earned about the causes of algal blooms, and it certainly would be preliminary to try to pinpoint these causes at this time.

A seminar on algae[4] was given in April 1960 at the Robert A. Taft Sanitary Engineering Center in Cincinnati which seems to support this position of uncertainty. For example, one speaker, Prof. H. K. Phinney, Oregon State College gave a paper on a problem which exists at Klamath Lake in Oregon. This lake receives essentially no domestic wastes, yet for over 60 years summer algal blooms have been intense. This is a case where natural enrichment causes the growth. Repeated chemical analyses of the water from many sampling stations failed to establish chemical factors which might explain the problem. The water was low in calcium, very low in dissolved phosphorus, high in chloride. Thus, very important sources of nutrients other than domestic sewage are definitely indicated.

Somewhat along the same line, another speaker at this seminar, Prof. R. O. Sylvester, Univ. of Washington, pointed up the extreme importance of drainage from forests and agricultural lands as sources of nutrients which can cause algae blooms. He presented data which showed that considerable amounts of both nitrogen and phosphorus result from run-off following rainfall, with agricultural lands showing the higher amounts, as would be expected.

Other interesting points brought up in this seminar included the statement by Dr. R. W. Krauss, Univ. of Maryland that so little is known concerning the nutritional requirements of algae, that even knowing the chemical makeup of waters, it is impossible to predict growth. At one point he also noted that polyphosphates are not suitable growth factors for algae. The types of phosphates used in detergents are, of course, polyphosphates.

Another speaker, Dr. Provasoli, Haskins Laboratory, noted that vitamins are required as growth factors with certain algae, and recommended that this factor be given increased attention. Still another speaker, Dr. G. W. Lawton, Univ. of Wisconsin reported that at the end of the first year of the diversion of domestic wastes around Wisconsin lakes, essentially no difference in the chemistry of the lake water is evident, although several new strains of algae have appeared. It is recognized, however, that this is a relatively short time in which to expect significant chemical charges.

All in all, the seminar pointed up the fact that a great deal needs to be learned before all of the factors controlling algal growth are known.

Still on the algae question, there are at least two additional literature references which bear on the question of phosphate contribution to algae growth. The work of Gerloff and Skoog at the University of Wisconsin[5] indicated that both the nitrogen and phosphorus contents of samples collected during periods of algae blooms in Wisconsin lakes were in the range of luxury consumption; in other words, they were very much higher than the minimum levels necessary for algal growth. The concentration of algae which might be considered a good lake bloom is quite low, approximately 10 mg of algae per liter.

Consequently, very low phosphorus concentrations apparently can support substantial blooms in natural waters. This raises questions as to the true significance of phosphorus derived from detergents, since without the detergent contribution sufficient phosphorus may already have been present from land drainage and other sources.

Also, there is some evidence that if the phosphorus content is increased beyond the minimum levels necessary to support good algal blooms, a heavier bloom does not result. Work by Dr. Fitzgerald at Wisconsin showed that there was no difference in the growth of one strain of algae, *Chlorella pyrenoidosa*, whether it was in an effluent containing 7.3 mg/l phosphorus or in the same effluent with three-quarters of the phosphorus removed; i.e., to 1.8 mg/l[6].

Although a great deal remains to be learned concerning the relative importance of the various nutrients, there does appear to be general agreement that regardless of source nitrogen and phosphorus are factors. Thus it would appear desirable to remove them, and one way which has been suggested is through use of oxidation ponds.

The review article by Fitzgerald and Rohlich on stabilization ponds[6] discusses the effectiveness of these ponds in removing nutrients. They report that ponds can achieve 75-90 per cent of reduction ammonia nitrogen, 60 per cent organic nitrogen and 96 per cent phosphorus. The phosphorus is believed to be precipitated out by the increased pH of the ponds, rather than removed by absorption by the algae. They point out that it might be possible to harvest the algae and sell it as a food supplement, chicken feed, or as a source of industrial raw materials. Harvesting, of course, would permanently remove any nutrient materials from the water which might be later released from dead algal cells.

Frothing Problems

The second of the two Canadian problems believed associated with detergents, or more accurately the surfactant material from detergents, is that of frothing on sewage treatment plants. In this area the Soap Association has sponsored some research, and it may be possible to provide more helpful information than in the case of algae. A project on the causes of frothing, and the means by which it can be eliminated or controlled, is being supported at the University of Wisconsin.

In many ways, this has been the most difficult of the various projects sponsored by the Association, because separating out, and even identifying, the various factors involved is a considerable problem. Some of these factors still haven't been established; however, much progress has been made.

To date the Wisconsin Project has established that while the surfactant ABS is one of the factors which contributes to frothing, many others, either independently or combined.

also are involved. For example, low suspended solids concentrations promote frothing, as has been recognized since the San Antonio studies a number of years ago.[7] Protein degradation products, present in almost every domestic sewage, also contribute to the frothing problem. In addition, elevated temperatures, over 70°F, and high pH values are somehow involved. Aeration rates play a role, and the conditions during low flow periods, particularly at night when ABS levels in the influent are certainly low, somehow promote the problem.

The degree to which each of these, and undoubtedly other, factors is contributing to frothing still has not been established. Nor is the actual mechanism known by which such materials as ABS and complex nitrogen compounds do contribute. It certainly isn't the simple matter of lowering surface tensions, because at the low concentrations of 10 mg/l or under the surface tensions are hardly affected. To our knowledge, no one has ever established a relationship between frothing and surface tension measurements in aeration tanks.

At present at Wisconsin they have designed a rather unique laboratory-scale continuous-flow activated sludge plant, Fig 2, in which an experiment is being run which will permit statistical interpretation of the factors being tested. These factors are 1. suspended solids, 2. detention period, 3. aeration rate, 4. ABS in feed, 5. BOD in feed, and 6. nitrogen: BOD ratios. High and low conditions or concentrations of each factor are included. A total of eight separate runs is required, and since each run requires as much as three to six weeks, and some have to be repeated, completing the study takes a long time.

It is not planned to submit the data to statistical analysis until the entire test is complete. However, it is interesting to note in passing that the incomplete results suggest that reduced frothing may be associated with lower aeration rates and extended detention periods. This cannot be considered conclusive at this time, however. Overall, it is hoped that out of this work may come the defining of operating conditions which will minimize frothing for the factors which exist and cannot be controlled, at any given time.

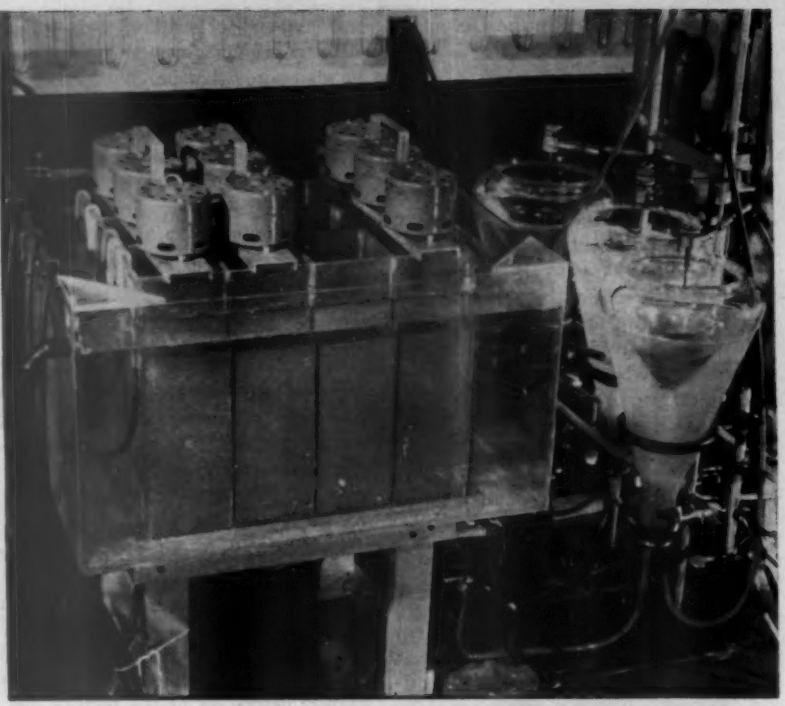

Fig 2 A LABORATORY SCALE experimental activated sludge unit developed to obtain data for the statistical analysis of the frothing problem

In general in the U.S. while frothing is recognized as a nuisance problem, it has not been generally associated with poorer plant performance. Operators keep it under control by maintaining high solids levels in the aeration tanks, or with sprays or defoamants. Much of the Wisconsin work has been published in *Sewage & Industrial Wastes*.[8]

Other Soap Association Research

It was mentioned earlier that the Association has supported other research in both the water and sewage treatment fields.

For example, projects at the Massachusetts Institute of Technology[9,10] and the University of California[11] have dealt with the fate of ABS in sewage treatment, and with attempts to improve the 50 per cent or better which currently is removed in primary and secondary treatment. The MIT people demonstrated up to 80 per cent removal on a laboratory basis with a complete mixing modification of the activated sludge principle; however, one attempt to modify an existing plant to this system has not yet been successful. The California people have demonstrated, also in the laboratory, as high as 90 per cent removal by deliberately frothing effluent from aeration tanks, followed by removal and separate disposal of this froth; this technique has yet to be applied to an operating plant. Both processes offer the promise of improved ABS removal if they can be adapted to large scale practice.

The area of water treatment has received considerable attention in the Association's research program. At Johns Hopkins University,[12] a project was carried out to determine effective and economic means for removing trace quantities of ABS from water supplies, should it ever become desirable. A number of materials which might serve as ABS adsorbing agents were evaluated, with activated carbon turning out to be the most effective. It was also found that different carbons have different effectiveness. It appears that, for ABS concentrations in the range of 0.2 to 2.0 mg/l, from 40 to 90 mg/l of a good carbon will remove 90 per cent of the ABS in the water supply.

It should be pointed out that, at least in the U.S., the levels of ABS in surface waters are very low, 0.5 mg/l and under.[13] The results of a weekly monitoring program which has been carried out since 1954 by Procter & Gamble on the Ohio River just below Cincinnati have shown an

average of only 0.16 mg/l apparent ABS, and there has been no tendency to increase during this entire period.[14] Similarly, two surveys of the drinking waters of 32 major U.S. cities serving an estimated population of 25 million have shown an average ABS content of 0.03 mg/l with samples ranging only from 0 to 0.14 mg/l.[15] These are certainly low, and insignificant levels.

The other Association project in the water area has dealt with the phosphate component of synthetic detergents, not as it relates to algae growth, but as this component might affect water treatment. This project was carried out at the University of Illinois. Studies were undertaken to 1. survey typical streams in the State of Illinois for the amount and type of phosphate present, and 2. determine whether the existing concentrations might have any effect on conventional water treatment operations. This latter phase stemmed from laboratory work which had suggested that the complex phosphates used in detergents could, at relatively high concentrations, interfere with coagulation and settling.

The survey of Illinois streams, using the improved phosphate analytical procedures developed by the Association, showed that phosphate concentrations were low, with the complex phosphates generally less than 0.5 mg/l as P_2O_5, and the ortho phosphate content about the same. It was also determined, and this is very important, that almost half of the total phosphate present comes from the drainage of agricultural land. This concurs with the findings reported at the algae seminar which were discussed earlier.

Laboratory studies on coagulation and settling showed that the 0.5 mg/l level of complex phosphates had an effect on this process which was barely perceptible, and that this could be overcome readily by either a moderate increase in coagulant dosage or an increase in settling time.

Other laboratory studies showed that the complex phosphates will degrade to the simple ortho form in the presence of stream biota, the rates of degradation varying according to the physical, chemical and biological conditions encountered.

Overall, the Illinois work showed conclusively that the phosphate levels found in Illinois streams have no practical significance on water treatment, and further that only a portion of the phosphates present can be detergent-derived.

The Illinois work has been published in four separate papers.[16] [17] [18] [19]

Safety of Synthetic Detergents

Questions are raised from time to time concerning the toxicological aspects of ABS, and occasionally, the polyphosphates.

The Soap Association has made a thorough review of the literature concerning ABS toxicity. This review, entitled *ABS and the Safety of Water Supplies*, has been published in the JAWWA.[20] The literature, covering acute and sub-acute toxicity experiments, shows in all cases an adequate factor of safety for ABS, considering the levels in water supplies.

In addition, a two-year chronic study of the effect of ABS in rats has been completed by Hazelton Laboratories and P&G, and has been published in *Toxicology and Applied Pharmacology*.[21] In this chronic study, levels of 1000 mg/l and 5000 mg/l were fed in the diet, and the weight equivalent of 1000 mg/l was fed in drinking water, to three different groups of rats. No evidence of toxicity was noted, and it was the conclusion of the authors that "to the extent that animal tests provide a basis for the assay of toxicity to humans, it would appear . . . . . that considerable amounts of ABS (much in excess of the amounts that might find their way into the drinking water) could be consumed over long periods without harm".

Of interest also are the limits being proposed for the current revisions of the U.S. Public Health Service Drinking Water Standards.[22] A limit of 0.5 mg/l ABS is proposed, based on aesthetic rather than safety reasons. The two reports mentioned above have been submitted to the Toxicology Subcommittee of the USPHS reviewing these Standards, and the fact that the ABS limit has been publicly proposed without toxicological comment suggests that they agree that the factor of safety demonstrated by the rat feeding experiments is more than adequate.

On the question of the safety of phosphates, the U.S. Food & Drug Administration has cleared both the polyphosphates used in detergents, and the ortho form to which polyphosphates degrade, for use as food additives.[23] This would appear to establish without question the safety of these materials.

Conclusions

This, then, briefly covers the activities of the Soap Association regarding the various questions raised in the U.S. on detergents and their role in water and sewage.

In general, it is believed the Association research program has shown that synthetic detergents are not responsible for all of the problems of which they were once accused.

The fact that ABS is removed to an appreciable extent in secondary sewage treatment has been established and methods for improving that removal in sewage treatment, as well as removing it from water, have been devised.

In aeration tank frothing, ABS is by no means the only contributor; in fact, the other factors are so important that merely by themselves they might create a definite problem.

ABS has been shown to have a toxicological factor of safety many times the concentrations which might occur in water supplies. Phosphates also are known to be safe.

Phosphates have been shown to cause no serious problems in water treatment plant operations.

The role played by phosphates derived from synthetic detergents in promulgating algae blooms is not clear. It is evident, however, that natural drainage from agricultural lands and forests can contribute significant amounts of nitrogen and phosphorus to streams and lakes, and these sources should be considered along with domestic wastes when studying specific problems.

In any event, the Association's broad research program is continuing, and as more facts are developed it is hoped that they can be used both to eliminate any problems where detergents are involved, and to further answer the many other problems of concern to the people in this extremely important field.

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Improved wastewater treatment is possible, as well as the . . .

Syndet Removal from Drinking Water *using Activated Carbon*

by MAXIM LIEBER, Prin. Sanitary Chem.
Nassau County Dept. of Health
Div. of Laboratories and Research

RESUME: Mounting use of syndets and their increasing prevalence in both ground and surface waters dictate action to combat resulting water quality deterioration. This work with activated carbon describes reduction in syndet content of a ground water supply and suggests its use at wastewater treatment plants.

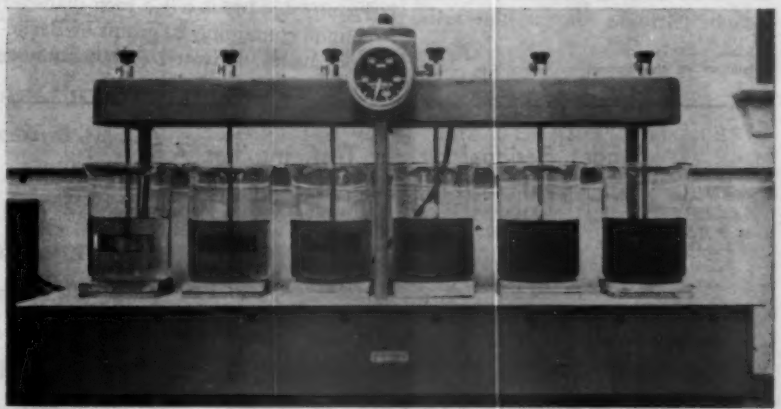
■ SURFACE-ACTIVE AGENTS, exhibiting detergent properties, are now in common use by industry and in the home. As a result, the presence of synthetic detergents has become more apparent in our waterways and streams throughout the country. Also, in areas such as Nassau and Suffolk counties in New York, the ground waters have been found to contain varying quantities of synthetic detergents. Here, the sand and gravel soil serves as a good source of water supply and an ideal medium for the disposal of sanitary and industrial wastes.

The detection of industrial waste contaminants has become more prevalent in ground water aquifers,[1,2] but many of these can be removed by adequate industrial waste treatment before discharge to the ground. However, the common use of syndets in home and industry, with its ultimate disposal to cesspools along with sanitary and industrial wastes, presents a far more complex situation. The literature is extensive on the existing difficulty in removing syndets by conventional sewage treatment methods. The normal biological degradation of organic wastes in cesspools is also ineffective in the decomposition of synthetic detergents. This has been confirmed by observations made in a study completed in Suffolk County.[3]

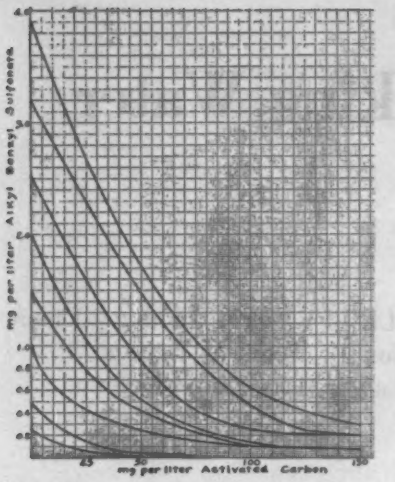
In the Long Island area there has been a rapid rise in the population densities. This has been accompanied by increased construction of residential homes, many of which have their individual cesspool or septic tank. Some of these homes also have their own private shallow wells as a source of water supply. The detection of the synthetic detergents in the shallow wells discloses what is occurring to the shallow ground water table and what may be anticipated for the future in deeper ground water aquifers. Once these syndets pass unaffected through the cesspools, the possibility of any additional degradation or decomposition taking place is nil. Consideration must therefore be given to the possibility of their removal. A water supply containing 1.0 to 1.5 mg per liter of detergent as Alkyl Benzyl Sulfonate (A.B.S.), possesses taste characteristics detectable by many individuals. That, plus the foaming effect noted on agitation makes such a supply unpalatable.

Activated carbon has been employed for concentrating syndets in the methodology of laboratory analytical procedures. Since this method of concentration and separation of synthetic detergents from water is very effective, an attempt was made to determine the potential of utilizing activated carbon in water supply treatment for syndet removal.

A standard suspension of activated



STANDARD PADDLE MIXER was used to distribute activated carbon dosages in water samples containing syndets.



REMOVAL OF A.B.S. in Jar Tests using Activated Carbon.

carbon was prepared containing 10 grams of Nuchar W* per liter of distilled water. One milliliter of the carbon suspension per liter of water will give a concentration of 10 mg per liter of activated carbon. Jar tests were made on distilled water dilutions of shallow well waters containing synthetic detergents. With each prepared dilution, varying quantities of activated carbon were used. The paddles on the mixing machine were set to rotate at 100 rpm for three minutes and then at 50 rpm for seven additional minutes. The test samples were immediately filtered. The methylene blue extraction procedure[4] was used to determine the syndet values in both the raw and treated waters.

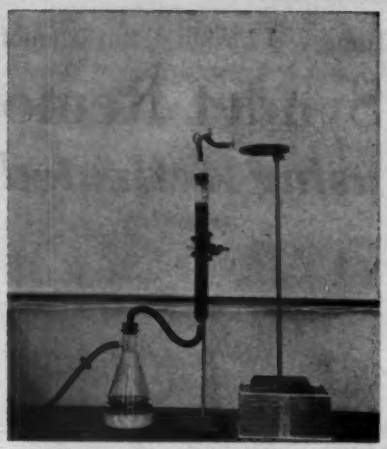
Table 1 contains the observed data. This information was plotted in Figure 1. For all practical purposes, the adsorption of syndets by activated carbon follows the Freundlich Equation. Thus the latter traces of syndet are more difficult to adsorb than the earlier portions, or, as the syndet concentration of a water supply increases, a higher carbon dosage will be necessary to accomplish the desired removal. This increased carbon dosage is not proportional to the increased syndet value of the raw water. It is interesting to note that the plant application of activated carbon for taste and odor control has been shown to be more efficient than that found in laboratory tests. Similar efficiencies may be anticipated for the removal of syndets on a plant scale to the extent of using approximately 25 per cent less activated carbon.

This type of treatment would necessitate a plant employing mixing and settling basins and possibly a filtration unit, but such elaborate treatment procedures are not practical for the Long Island ground waters. The quality of these waters has always been excellent, since the soil is principally sand and gravel. Water obtained from properly placed and constructed wells is generally free of bacterial contamination and in some instances is pumped directly from the well into the distribution system without treatment. In other instances, chlorination is practiced to retain a chlorine residual for protective purposes.

The individual home owner with the private shallow well is the one who is currently experiencing difficulty with syndet contamination. It would be advantageous to find a practical treatment procedure that could be used to remove syndets from these well supplies.

Experimental Apparatus

A laboratory treatment unit was assembled utilizing a column of granular activated carbon, as shown in Figure 2. This is a 1.5 inch diameter column containing 80 grams of Barnebey-Cheney activated carbon number SC5. Experiments were conducted using well waters containing high syndet values such as 2.12 and 6.4 mg per liter as A.B.S. On passage through the carbon column, there was a high percentage of syndet removal producing filtrates of 0.03 to less than 0.02 mg per liter as A.B.S. Passage through the column was accomplished both by gravity flow and suction. In both cases the removal was equally efficient.



LABORATORY APPARATUS showing reservoir and column of granular activated carbon.

An attempt was made to apply this treatment on a practical scale. A small filter bed of granular activated carbon was fabricated as illustrated in Figure 3. This bed was constructed of 2 inch galvanized pipe, filled with 250 grams of Barnebey-Cheney activated carbon number SC5 and accommodated with garden hose hardware on either end. The carbon bed inside this pipe rested on glass wool placed as a strainer at the bottom of the filter. The influent end of the filter had a valve used to regulate the flow of water into the column. A pressure gauge was tapped to the bottom of the filter to measure the effluent pressure from the carbon bed. The depth of the carbon bed was approximately 10 inches.

A private well supply was chosen which contained a syndet contaminant. This well was 30 feet deep and located approximately 30 feet south of a cesspool. There were no other cesspools within 125 feet of the well. Past ground water studies established the ground water flow in the area to be in a southeasterly direction. The well was driven 18 months prior to the study, but six months after

*Product of the Barnebey-Cheney Co.

Table I
Syndet Residual by Jar Test, mg/Las A.B.S.

Raw Water mg/liter as A.B.S.	Remaining After Dosage of — mg per liter Activated Carbon									
	5.0	12.5	25.0	37.5	50.0	75.0	100.0	150.0	200.0	250.0
0.25	0.19	0.13	0.06	0.05	<0.02	<0.02				
0.48		0.30	0.15		0.04	<0.02	<0.02	<0.02		
1.02			0.40		0.24		0.10	0.08	0.03	0.03
1.48			0.76		0.45		0.10	0.06	0.04	0.02
2.00			1.03		0.52		0.14	0.07	0.04	0.02
2.52			1.56		0.85		0.24	0.19	0.03	0.03
3.18			2.28		1.48		0.45	0.20	0.10	0.08
3.90			2.60		1.80		0.62	0.29	0.20	0.09

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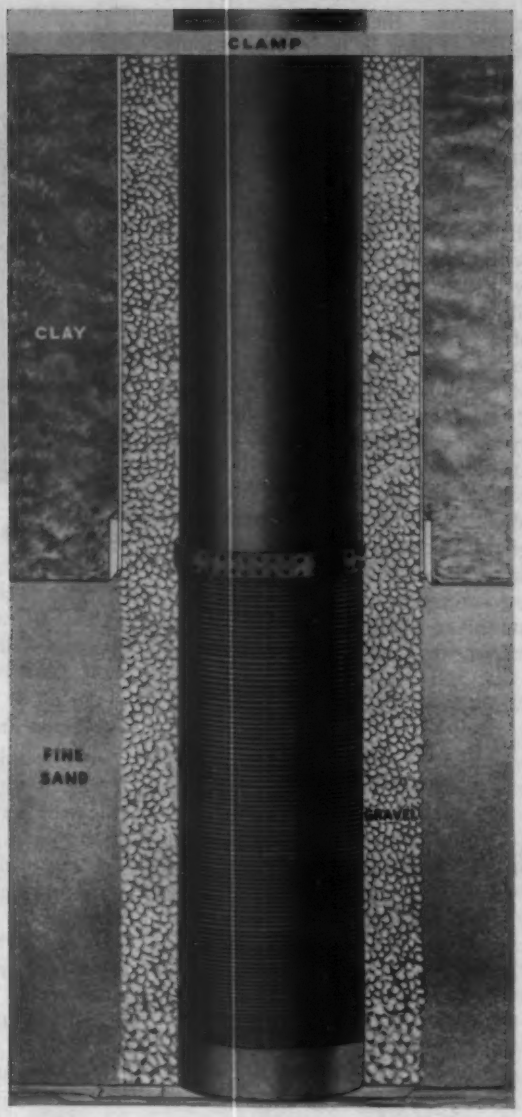

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installation, the owners detected a taste and odor in their water supply.

Bacteriological water samples collected from both the kitchen and bathroom water taps indicated the water to be free of Coliform contamination. These results were consistent with those noted in other private shallow wells that are contaminated with syndets. The water from the test well was passed through the carbon filter bed with an effluent pressure of 5 to 8 psi and samples were collected for syndet analysis at intervals of 5 gallon treatment periods. Table 2 is a tabulation of the samples and syndet values obtained on analysis. It is interesting to note that the syndet content of the raw water increased slightly with pumping. Since the origin of the contaminant is from the adjacent cesspool, this slight increase on continuous pumping is conceivable. The ability of activated carbon to remove syndets is evident. In fact, its effectiveness is more apparent when it is realized that the raw water was passed under pressure through a short column of activated carbon.

Table 2

Results of Test Runs on Carbon Filters Using Water from Shallow Well

Sample Number	Description of Sample	mg per liter as A. B. S.
1	Raw Water at Start	1.32
2	Treated Water 2nd. Gal.	0.02
3	Treated Water 5th. Gal.	0.03
4	Treated Water 10th. Gal.	0.05
5	Treated Water 15th. Gal.	0.07
6	Treated Water 20th. Gal.	0.12
7	Treated Water 25th. Gal.	0.10
8	Treated Water 30th. Gal.	0.13
9	Raw Water 30th. Gal.	1.36
10	Treated Water 35th. Gal.	0.10
11	Treated Water 40th. Gal.	0.10
12	Treated Water 45th. Gal.	0.15
13	Treated Water 50th. Gal.	0.16
14	Treated Water 55th. Gal.	0.15
15	Treated Water 60th. Gal.	0.15
16	Raw Water 60th. Gal.	1.36
17	Treated Water 65th. Gal.	0.15
18	Treated Water 70th. Gal.	0.21
19	Treated Water 75th. Gal.	0.18
20	Treated Water 80th. Gal.	0.34
21	Treated Water 85th. Gal.	0.30
22	Treated Water 90th. Gal.	0.30
23	Raw Water 90th. Gal.	1.40
24	Treated Water 95th. Gal.	0.28
25	Treated Water 100th. Gal.	0.30
26	Raw Water end of Run	1.40

PRACTICAL SIZE activated carbon column for home experiment.

Two-Stage Treatment

An examination of the data in Figure 1 would indicate an increased efficiency for syndet removal by use of a double stage treatment process. To verify this, a water containing 1.89 mg per liter as A.B.S. was treated with graduating quantities of activated carbon to give a satisfactory degree of removal. These data are presented in Table 3. Several proportionate quantities of the activated carbon dosage were then used on the raw water in a two stage treatment. The most satisfactory result was obtained by treating the raw water with 50 mg per liter of activated carbon in the first stage. The filtrate of the latter stage was again treated with 50 mg per liter of the carbon. These data show that a two stage treatment of this water accomplished satisfactory treatment with half the original anticipated carbon dosage. This also implies that greater removal efficiencies may be predicted with the use of a carbon filter bed with a counter current flow system.

Conclusions

Consideration should be given to the potential use of activated carbon for syndet removal for home and larger water treatment plants. The adsorption of syndets by activated carbon should also be considered to eliminate the foaming problem encountered in the aeration tanks of activated sludge plants. Other treatment plants would also be capable of producing a sewage effluent relatively free of detergents before their discharge into the fresh inland waterways.

Table 3

Two-Stage Activated Carbon Treatment

Raw Water plus mg per L Activated Carbon	Filtrate mg per L as A.B.S.
0	1.89
25	1.00
50	0.58
100	0.15
150	0.11
200	0.07
250	0.03
Successive Treatment	
50	0.39
50	0.06

References

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2. Lieber, M. and Welsch, W. F., "Contamination of Ground Water by Cadmium," *Jour. A.W.W.A.*, Vol. No. 6, (June, 1954) p. 541.
3. Flynn, J. M., Androli, A. and Guerrera, A. A., "Study of Synthetic Detergents in Ground Water," *Jour. A.W.W.A.*, Vol. 50, No. 12, (December, 1958) p. 1551.
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Water wells in glacial drift may cost less and produce more using . . .

Reverse Circulation Drilling

by N. E. Gunderson
Layne-Northern Company
Mishawaka, Indiana

EDITOR'S NOTE: Improvements in water well drilling techniques do not occur very often. While reverse circulation drilling methods are not new, in fact some may consider them modifications of rotary procedures, there still remains the problem of tool standardization. If more water can be produced at less cost, reverse circulation drilling can make a substantial contribution to water production know-how.

■ REVERSE CIRCULATION drilling, applied principally to water wells in glacial drift, is a variation of rotary drilling used in the oil fields for a number of years. This newer method is particularly interesting because basic changes in well drilling methods occur infrequently.

Two principal motions can be applied to drilling tools at the surface of the ground. The first and oldest is the drop tool method used by the Chinese several thousand years ago. Tools and equipment have been improved, but basically it still consists of lifting and dropping a string of tools. There are definite limitations of depth, with the deepest hole being approximately 7,000 feet.

Rotary drilling first came into use about fifty years ago and opened up the Texas oil fields. The hole is drilled with a rotary motion of the tools and the hole is filled with fluid which holds the hole open during drilling. Holes have been drilled by rotary to approximately 20,000 feet. Rotary drilling is best adapted for deep, small diameter holes. In contrast, reverse circulation has only been in use about 20 years. Particularly adapted to large diameter water wells in glacial drift, the approximate maximum depth is 1000 feet. This method is properly named reverse circulation because the liquid is drawn up through the drill rods under vacuum while in the earlier rotary method the liquid was pumped down through the drill rods under pressure. In addition the main features of reverse circulation drilling are practically opposite to the features of rotary drilling.

Principle advantages of reverse circulation over rotary drilling are larger diameter wells at less cost and less power required for drilling. Compared with cable tool drilling, reverse circulation also provides larger diameter at less cost and an open hole in which material may be freely raised or lowered to correct position. Further, the well casing may be cemented from top to bottom, if desired. Wells drilled by reverse circulation show increased yield over wells drilled by cable tool or rotary.

Both rotary and reverse circulation drilling in glacial drift use a drilling fluid to carry the cuttings to the surface and to hold the hole open. In rotary drilling, the drilling fluid is usually a mud considerably heavier than water so that the hydraulic problems in handling underground water are almost eliminated. However, it is fairly common practice in reverse circulation drilling to use clear water for the fluid which provides an excess pressure to counterbalance the water in the formation outside the hole.

Discharge And Recharge Wells

In order to demonstrate the problems in this hydraulic balance, it will probably aid to consider first, an artesian discharge well and second, an artesian recharge well. A discharge well takes water out of a formation and a recharge well puts water back into a formation.

Consider the case of a well pumping from an artesian formation. The term artesian refers to a water-bearing formation full of water and that the formation has a clay cover. The static water level in any hole penetrating this formation will lie above the top of the formation. It is common practice to report a test of this type well by quoting the amount of water level decline for a given quantity of pumpage. This decline is called the drawdown. Pilot wells located at varying distances from the pumped

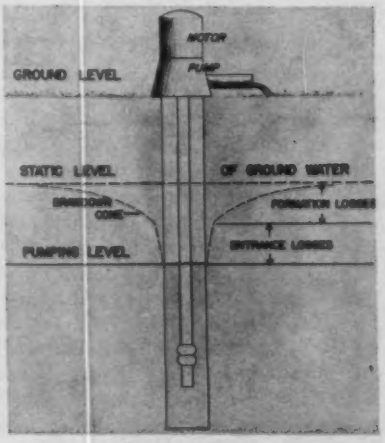

FIG. 1. DISCHARGE WELL showing drawdown cone and relationship between formation and entrance losses during pumping.

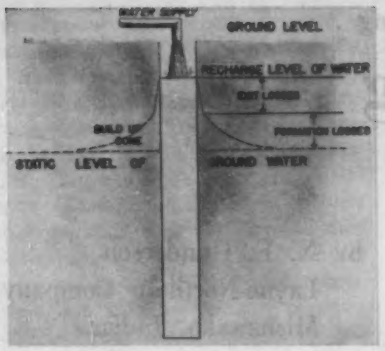

FIG. 2. RECHARGE WELL showing build-up cone and relationship between formation and entrance losses during recharging.

well would also have drawn down and the water level indicated by these pilots would assume the shape of an inverted cone. This is commonly called the drawdown cone, Figure 1, or cone of depression. The cone's shape is determined by the characteristics of the formation and is not affected by the type of well construction. The yield in gpm divided by the total drawdown input gives gallons per foot of drawdown, or specific yield of the well.

If the pump is removed from this same artesian well and water is poured into the well, an artesian recharge well is produced. The action of this recharge well should be, for all practical purposes, the reverse of the action of the discharge well. There has been very little discussion or standardization of terms on recharge wells so we might use the word take to express the gallons per minute of water added to the recharge well. The take in gpm divided by the build-up in feet gives the specific take of the well. The static level can be multiplied by the specific take to obtain the approximate flow of water required to fill the well and to keep it full.

If water is added to a recharge well at a constant rate, a cone will be built upwards instead of downwards as in the drawdown cone. For lack of a better term this may be called the build-up cone, Figure 2, as opposed to the drawdown cone. In the discharge well the drawdown cone and also the drawdown itself can very properly be divided in two parts. First is the drawdown cone due to the friction losses in the formation itself, which are practically independent of the well construction. Second, there is the portion of the drawdown and the drawdown cone which is due to the entrance losses into the well caused by friction in the screen and in the formation immediately surrounding the screen.

In the recharge well the feet of build-up or the height of the build-up cone can also be divided into two parts which consist of friction losses in the formation itself and exit loss due to the water flowing through the screen and through the formation immediately around the screen, as illustrated in Figure 3. Extremely important, this exit loss is the one factor making it possible to drill a hole and hold it open with clear water without using a well casing. If a completed artesian recharge well is kept in service, it would be possible theoretically to remove the casing and the wall of the hole would stand up indefinitely until the water supply was cut off.

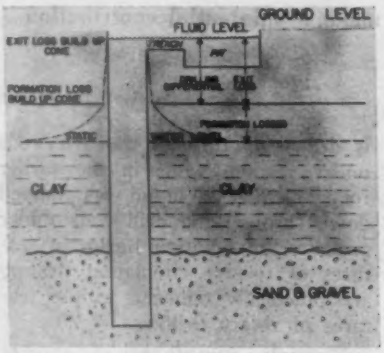

FIG. 3. HYDRAULIC CONDITIONS required during reverse circulation drilling. Fluid level in pit determines head required to hold well hole open.

The above examples describe how a fluid process can be used to hold a hole open if fluid is continuously supplied to the hole to maintain an internal pressure greater than the external pressure. Figure 4 illustrates a typical reverse circulation drilling system. The take or flow into such a well is actually leakage through the wall of the hole. A pit provided adjacent to the well will hold the water level at ground surface. The amount of water to provide this take in the well is usually considered as make-up water into the pit. Since the hole is full of fluid which holds the hole open, it is a very simple matter to pump the fluid into the hole or out of the hole and remove the cuttings from the bottom of the hole during drilling.

Planning Required

Drilling by this method requires considerable engineering planning. It is a basic contradiction that, while drilling, a watertight hole is desired, while after it is finished, a leaky hole is necessary to make a good water well. In planning a job of this kind an accurate test well is essential. An electric log helps to insure that the proper formation is developed and gives some indication of probable yield. The most important information can be obtained from a special pumping test which would give the static water level and the shape of the drawdown cone developed around the well. Such a test will enable prediction of the yield of the finished well and the probable take while drilling. It is necessary to have this information before starting work, because a high static level may indicate that the hole will collapse before it is finished. A low static level may demand such a large take that sufficient water supply may not be available.

As was stated above, the exit loss is the differential which holds the hole open. Exit loss would normally be expressed in feet and for a given exit loss there would be a definite take in gallons per minute. The exit loss or differential varies approximately as the square of the take in gallons per minute. The distance from the static level to the water level in the pit is the maximum water head available. This head will be spent in overcoming the exit loss and the formation loss. The formation loss

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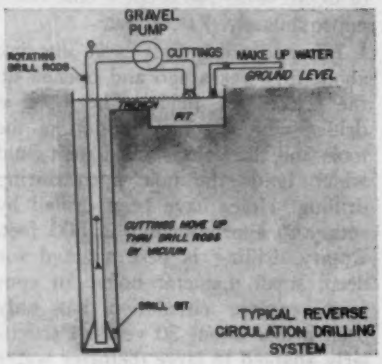

FIG. 4. SCHEMATIC ILLUSTRATION of typical reverse circulation drilling system. Note requirement for source of pit make up water.

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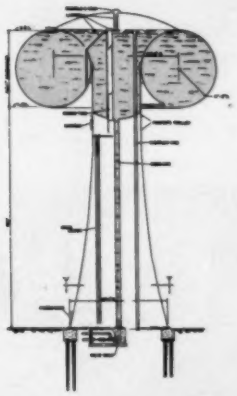

CAPACITIES AND DIMENSIONS

Capacity in Gallons	Tower Height to Low Water Level	Anchor Bolt Circle Diameter	Head Range	Torus Outside Diameter
3,000,000	100′	54′-6″	42′-0″	120′-3″
2,500,000	100′	52′-6″	39′-6″	112′-11″
2,000,000	100′	49′-6″	37′-0″	105′-0″
1,500,000	100′	46′-6″	34′-0″	94′-8″
1,000,000	100′	42′-0″	29′-6″	83′-6″
750,000	100′	39′-6″	26′-6″	75′-9″
500,000	100′	36′-6″	23′-0″	66′-9″
400,000	100′	34′-6″	21′-0″	62′-0″
300,000	100′	32′-6″	19′-0″	57′-0″

STANDARD FROM GRAVER

Capacity Gallons	Diameter	Head Range	Number of Columns
25,000	18′-0″	13′-9″	4
30,000	18′-0″	16′-6″	4
40,000	20′-0″	17′-10″	4
50,000	22′-0″	19′-0″	4
60,000	24′-0″	19′-0″	4
75,000	26′ 0″	21′-0″	4
100,000	28′-0″	23′-9″	4
125,000	30′-0″	25′-9″	4
150,000	32′-0″	27′-11″	4
200,000	36′-0″	29′-11″	4
250,000	40′-0″	29′-2″	5
300,000	44′-0″	30′-0″	5
400,000	50′-0″	30′-0″	6
500,000	55′-0″	30′-0″	7
750,000	61′-0″	40′-0″	8
1,000,000	70′-0″	40′-1″	10
1,500,000	104′-0″	25′-0″	12
2,000,000	112′-0″	30′-0″	16
2,500,000	122′-0″	30′-0″	16
3,000,000	124′-0″	35′-0″	20

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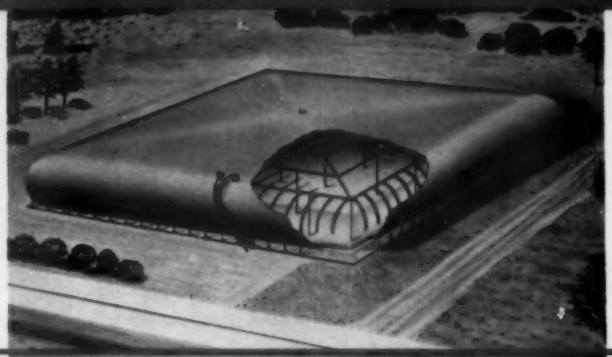

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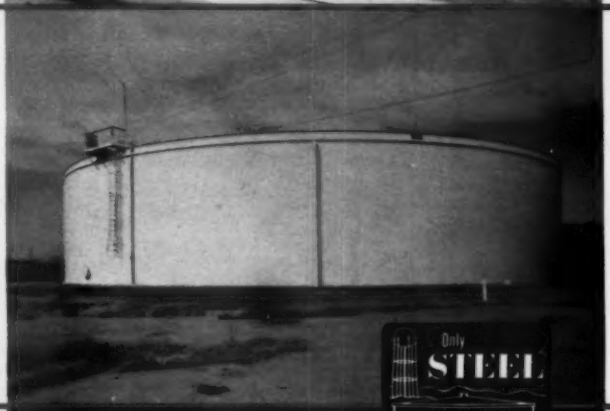

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Steel standpipes providing static head for water distribution systems—and often specified where pressure and volume needs exist together—are tanks having a greater height than diameter. Standpipes can be roofed with a variety of designs, and are often provided with architectural features such as colonnades. Since the size and capacity of standpipes depend on the requirements of the water distribution system, special design engineering services, to meet local requirements, are available from Graver.

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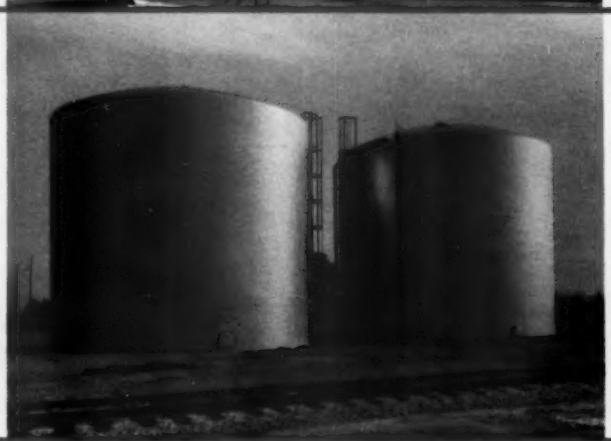
Rated Capacity Gallons	Actual Capacity Liquid Depth = Height—6″	Diameter	Height
100,000	100,470	27′-0″	23′-11½″
150,000	150,120	28′-6″	31′-11½″
200,000	200,730	33′-0″	31′-10½″
250,000	250,340	37′-0″	31′-7½″
300,000	300,550	42′-0″	29′-6″



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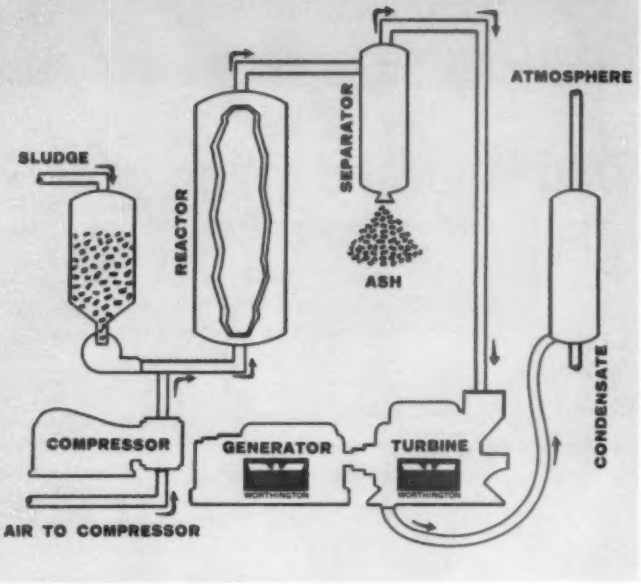

TURBINE GENERATOR KEY TO EFFICIENCY IN ZIMMERMANN PROCESS FOR HANDLING WASTE

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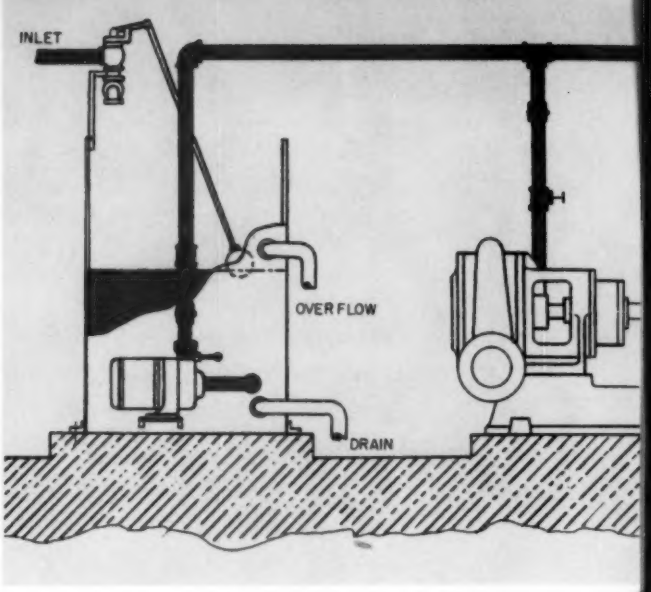
*The Zimmermann Process is patented and licensed by Sterling Drug Inc., New York, New York



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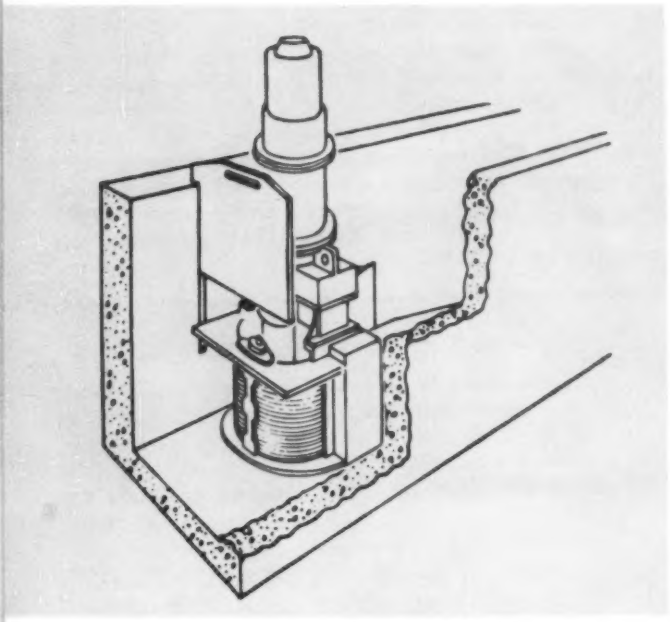

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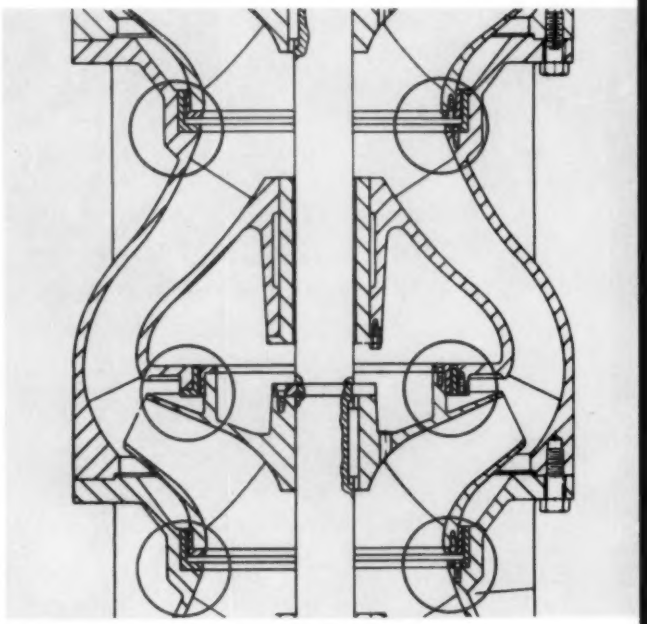
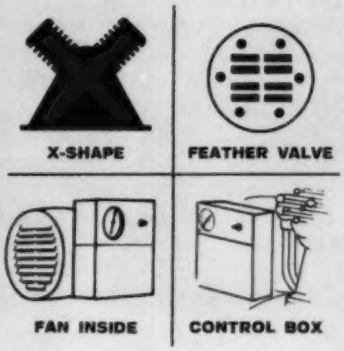


NEW HIGH HEAD, WET PIT PUMP DESIGN ELIMINATES HEAVY THRUST LOADS

This new line of high head, high capacity water works pumps has a new impeller design. The impeller has wear rings on front and back and is specially designed to balance out the vertical thrusts. The bowl has matching wear rings. This eliminates the necessity and cost for heavy motor thrust bearings. Capacity 15,000-70,000 gpm; heads to 350′. Circle 6 on card for more information.



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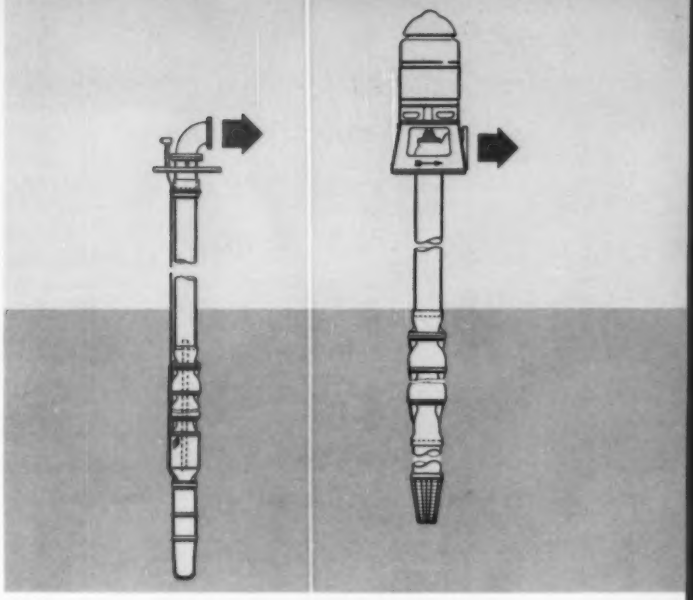

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CONTINUED FROM PAGE 128

is measured by the height to which the water level rises in the formation, just outside the bore hole. The difference between this height and the water level in the pit measures the exit loss which will keep the hole open.

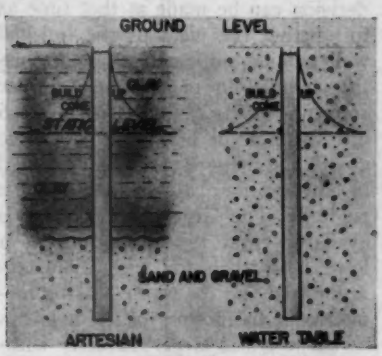

FIG. 5. COMPARISON OF build-up cones under artesian and water table conditions. Greater quantity of water is required to maintain build-up cone in water table.

Static Level

If nature provides sufficient height from static level to ground level, and a suitable formation to match, it may be possible to fill the hole with water and start drilling. However it may not be quite so simple and it is necessary to study the factors affecting this differential and learn how to control them effectively. The four possible factors are fluid height, fluid weight, fluid viscosity or flowability and wall friction. The fluid height can be increased by building up the ground surface or by operating a nearby dewatering well which would tend to pull the static level down at the spot where the well is to be drilled. Fluid weight can be controlled quite effectively with drilling clay since any required weight up to 15 or 16 pounds per gallon of drilling mud can be obtained. Fluid viscosity or flowability can be controlled in the same way by the addition of drilling clay and additives to obtain the desirable viscosity. Wall friction can be increased in several ways. The loose sand grains in the water while drilling tend to build up wall friction and the addition of drilling clays to the water builds up a substantial wall. Also because the wall friction is usually less at the fresh surface near the bottom of the hole, it may be necessary to drill intermittently permitting sand grains or drilling clays to build up wall friction.

The cone which builds up around an artesian recharge well has been discussed previously. The effect is largely one of pressure, since comparatively small quantities of water go into storage near the well. Under water table conditions a considerable amount of water must be poured into the formation to fill voids within the build-up cone, since in this case we have a free water surface within the permeable formation itself. The comparison is illustrated in Figure 5. Thus, under artesian conditions, the water level rises rapidly and under water table conditions the water rises slowly due to the time required to fill the cone. The difference in time may be as much as three or four days giving time to actually drill the hole before the cone is built up. Also, pumping tests on an artesian formation would enable accurate prediction of discharge well action in this ar-

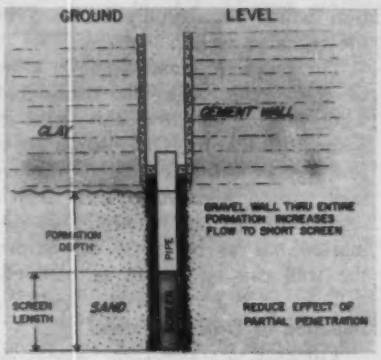

FIG. 6. VARIETY OF well completion procedures is permitted through use of reverse circulation drilling techniques. Possibility of cementing outer casing is important health consideration.

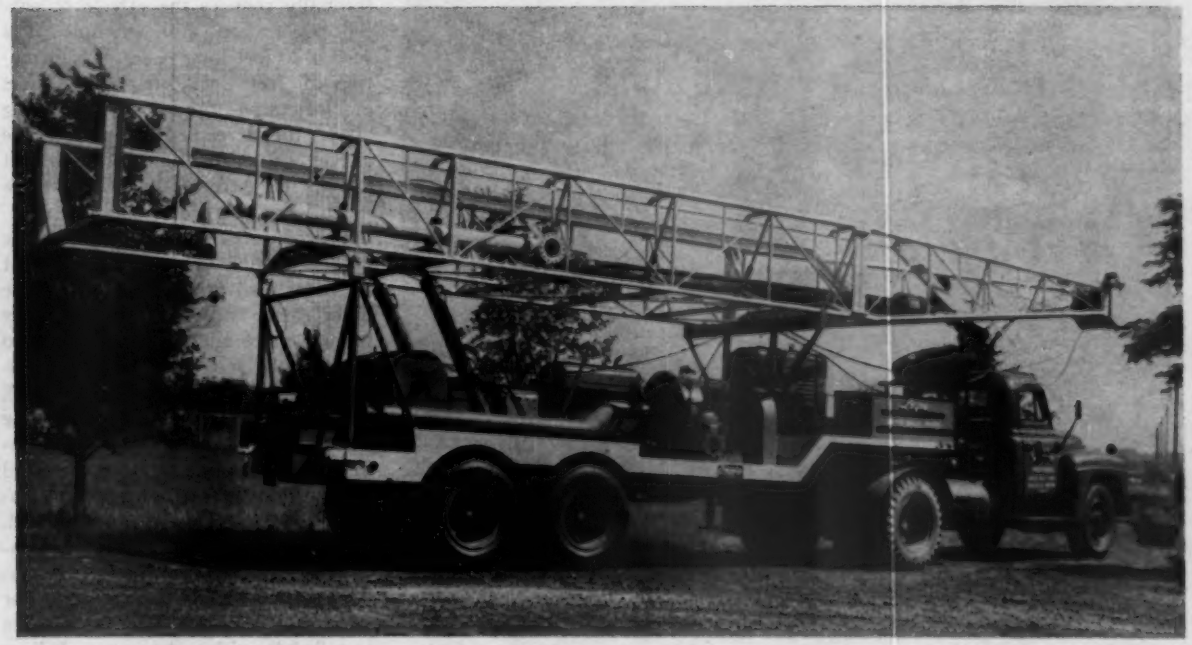

FIG. 7. PORTABLE RIG void in reverse circulation drilling is mounted on tandem axle semi-trailer. Note hydraulic jacks used in elevating tower.

tesian formation, because the actual formation to be used is under test. On the other hand, a test on a discharge well under water table conditions is only partially accurate for predicting how a recharge well will act. This is because the formation under test is only part of the formation which may finally be used in the recharge well.

The above explanation shows some of the problems to be considered when dealing with the static level in a single formation. Often there are a few feet of formation near the surface with a high static level which completely upsets the plans. This formation has to be cased off before the well can be drilled as planned.

Selection of Drilling Method

Although the hydraulic conditions outlined above apply equally well to rotary and reverse circulation drilling a closer examination reveals considerable differences between the two methods. The rotary drill operates at high speeds and produces fine cuttings but the reverse circulation drill operates at very low speed and literally plows the bottom of the hole. In the rotary method, the fine cuttings are floated up outside of the drill rods by a combination of velocity and viscosity. In reverse circulation, the coarse cuttings are pulled by vacuum up inside the drill rods principally by high velocity of clear water.

The selection of which method to use and which method is practical in glacial drift is determined to a large extent by the particle size in the formation to be drilled. This could be roughly explained by stating that the rotary either drills through or between the coarse particles. The reverse circulation method actually pulls coarse material through the rods so that large diameter of drill rods is necessary for large diameter material. Initial experimental work on this type of drilling was done with 7″ drill rods as standard equipment with an attempt to use 4″ and 12″ rods. After several years operation, it is evident that 7″ rods will drill about 85% of the wells and 4″ rods will handle about 15%. It appears at present that 8″ drill rods would be effective in Indiana and Michigan. However, 8″ drill rods require a 20″ hole to provide sufficient room for water to flow down outside the drill rods. Therefore, it appears that holes 6″ to 20″ diameter should be drilled by rotary process using 3″ or 4″ drill rods, and holes over 20″ diameter should be handled by the reverse circulation process using 8″ drill rods.

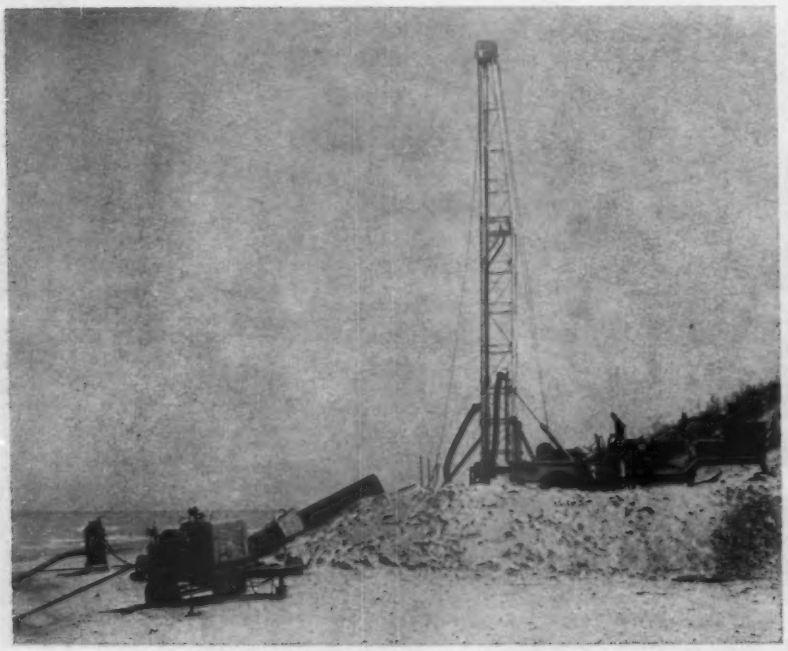

FIG. 8. INSTALLING 38" gravel wall well 60' deep on shore of Lake Michigan. Pit make up water was furnished from lake by pump at lower left.

Reverse Circulation Advantages

One of the principal advantages of reverse circulation drilling is that the hole is completely under control as long as it is kept full of water. The hole can be electrically logged upon completion and an intelligent decision can be made at that time as to whether the yield of the finished well will be sufficiently high to justify completion of the well. Either screen or casing can be easily lowered into the hole or lifted from the hole at will and the well can be constructed in any manner as planned by the engineer. The large diameter hole is available from top to bottom at a lower cost than for such diameters in the past and the water-bearing formation at the bottom of the hole can be cut to a still larger diameter without difficulty. This larger diameter results in some increase in yield, although not in direct proportion, and it permits gravel wall construction of practically any type. A coarse screen and a single gravel wall can be used in a medium formation. A double gravel wall can be used to handle the very fine sand formations with coarse silica sand against the formation and coarse silica gravel against the wide opening screen. Uniform porosity immediately around the screen results in low entrance losses and silica sand is insoluble in chemicals. Also, extension of the gravel wall above the screen substantially reduces the effects of partial penetration. For example, if a screen 20 feet long is set in a formation 50 feet thick, there is 30 feet of formation opposite the casing above the screen. However, if the gravel wall is continued for 30 feet above the screen the effect of a much longer screen is obtained without screen cost. The fact that the hole is completely under control at all times also permits cementing the outer casing which will undoubtedly become more and more important to the Health Departments. These possibilities are illustrated in Figure 6. A 15 pound cement slurry can be pumped from the bottom of the casing up or from the top of the ground down and the casing can be completely encased in cement if desired. The final and probably the most important advantage of reverse circulation drilling is the apparent better yield which is obtained over wells installed by either driving or baling. The only explanation we can offer

is that the hole is kept open by water and is not compacted as it is with driving or forcing screen or casing into the ground by other means. Possibly the fine drilling cuttings of the older methods are forced into the wall of the hole, resulting in lower yield.

Disadvantages And Problems

Reverse circulation equipment, Figure 7, is very heavy and one of the principal problems is to get equipment large enough to handle the work satisfactorily and stay within road limits. The latest mounted rig on a tandem axle semi-trailer weighs approximately 27,000 pounds with a 6" pump. About 20,000 pounds is centered on the rear tandem axle. This exceeds road limits in southern Michigan, so part of the rig is removed in wet weather. A similar truck mounted rig having tandem axles has 25,000 pounds on the rear tandem axles and simply cannot be moved in this area when road limits are imposed. Such limits may be more strict in the future. A complete reverse circulation drilling rig is shown in Figure 8.

There is still some question regarding pump selection, whether to use centrifugal or jet pumps. The jet pump is very tempting, because it provides a clear passage for water. It is an interesting sight to see a 6" jet pump delivering approximately 1400 gallons of water, sand and gravel into a pit. Present pumps are 6" and the next move would be to an 8" pump, though the writer does not know of any pump of this size in service. Larger pumps may require airlift to move the water and the cuttings. Change from a 6" to an 8" pump sounds small, but it will probably double the weight of many of the rig parts. Priming is a problem, whether to use pressure or vacuum, and operation of centrifugal pumps under vacuum can give difficulty, particularly in a portable unit. The drilling bits now being used for reverse circulation work are all home-made since there is no established manufacturer of the type required. There is hardly any agreement on the most effective type of bit and endless shapes and types are seen wherever this type of drilling is done. This is an extremely risky type of drilling in that a complete hole can be lost in 2 seconds. This, however, is not likely to happen if the hole has been carefully planned and if the engineer planning the hole fully understands the conditions which must be met. This type of work requires at least double the planning and supervision done on ordinary drilling work. This is illustrated by the fact that our supervisory group has increased 50% in the last two years, whereas the drilling force has remained constant.

The investment in equipment for recirculating drilling is approximately three times the investment in conventional cable tool equipment. For example, a cable tool rig which could do 80% or 90% of the cable tool drilling for water wells can be purchased fully equipped for approximately $8,000. The smallest complete reverse circulation rig with tools will cost approximately three times that amount. Our investment in the past four years has exceeded the investment during the previous 18 years, part of which is due to expansion, but principally due to adding reverse circulation equipment. As an interesting sidelight, we purchased one of the most modern reverse circulation rigs built to use 4" drill rods, which was almost a complete failure. The total cost would have paid for three college educations and we can say it has provided us a liberal education.

Progress

The search and development of ground water in this area has changed almost completely in the last five years. The following methods which may become well-established within a short time cover the entire field. Electrical Resistivity Surveys, where applicable, provide an initial survey to locate water without drilling more than one hole for calibration. For the balance of the test wells required, rotary testing provides high speed drilling and Electric Logging provides additional accuracy for rotary test wells.

The Aquifer performance test with one or more adjacent pilot wells indicates with reasonable accuracy the quantity of water to expect and guides proper well spacing. Reverse circulation drilling, as it becomes established, will provide more water at less cost from a permanent well.

It is no longer necessary to depend on theoretical arguments over screen construction or well construction. There are now available testing procedures such as step tests which actually measure entrance losses into a well and thereby demonstrate overall performance or well efficiency. A step test with two hours rest period, three hours pumping at half capacity and three hours pumping at full capacity will permit a close estimate of losses into the well due to turbulence. For high capacity wells these become the principal losses.

Probably the most important thing to keep in mind is that a careful ground water survey provides inforation which is just as valuable and as true 100 years from now as it is today and is a first requirement for intelligent planning of water works improvements.

This first of a two part article reports on recent advances in . . .

Evaporation Suppression Research

Part I

by JOSEPH B. FRANZINI
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EDITOR'S NOTE: One of the most interesting aspects of evaporation suppression research is that this is one of the few areas in which work is being done which, in a manner of speaking, can add to our supply of available water. It cannot, of course, add to the amount of rainfall, but it can increase the amount of rainfall available for our use.

In this article, Dr. Franzini reviews the work that has been done in the field and the accomplishments in this area to date.

■ THE WORLD'S INCREASING population and the always improving standard of living have resulted in a rapidly growing demand for water. In the United States in 1950 over 173 billion gallons of water were used each day. By 1955 that figure had jumped to 210 billion gallons per day, an increase of over twenty per cent in five years. It is very likely that by 1985 the daily demand for water in the United States will exceed 500 billion gallons, approximately double what it is today.

In this country, nearly 20 per cent of today's water comes from groundwater and 80 per cent from surface supplies; while less than 0.7 per cent is provided by reclaimed waste water. Fifty years from now a significant portion of our water will probably come from converted salt water; and reclamation of waste water may also become an important water source. Efforts to conserve water, to use it wisely, and to re-use it in industrial processes are becoming more apparent with each passing day. In this connection attempts have been made to develop means of reducing evaporation from reservoirs. Research to date indicates that the saving of valuable water by evaporation suppression may be economically possible under certain conditions.

The amount of water lost to the atmosphere by evaporation from reservoirs is sizeable. It has been estimated that the evaporation loss from water surfaces in the 11 Western States exclusive of Alaska and Hawaii averages about 11.5 million acre-feet a year, enough to supply the domestic needs of a city the size of San Francisco for more than 90 years. At Lake Mead behind Hoover Dam, the annual evaporation of over 800,000 acre-feet is enough water to keep the spigots in the City of Los Angeles running for almost two years. Evaporation loss from small storages, particularly stock ponds is often severe, sometimes exceeding the amount of water used.

Mechanics of Evaporation Suppression

Evaporation losses can be reduced by storing water in underground basins or in surface reservoirs that are relatively deep, by controlling water consuming plants that grow in and along the banks of surface reservoirs, by covering reservoirs, and by chemical means. There are drawbacks to all of these methods. Recharging underground basins presents many problems, most surface reservoirs are apt to be relatively shallow because of the natural topography of the area, and the control of water consuming plants is generally a costly operation requiring continuous attention. Moreover, covering a reservoir by structural means is very expensive and totally unfeasible for large reservoirs. The reduction of evaporation by chemicals presents many problems some of which will be discussed in the ensuing paragraphs.

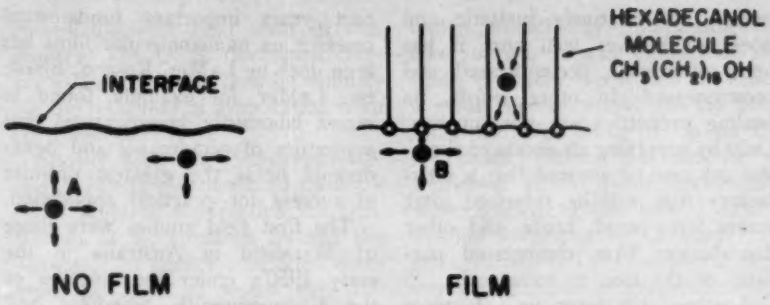


Fig. 1. THE MECHANICS of evaporation suppression.

Several years before the turn of the last century it was discovered that certain chemical compounds form a film one molecule thick on water surfaces. In the 1920's research by Langmuir, Schaefer, and others revealed that these monomolecular films could reduce evaporation. Some films were apparently much more effective than others. Recent investigations have shown that hexadecanol, $CH_3(CH_2)_{15}OH$, also known as cetyl alcohol, and octadecanol, $CH_3(CH_2)_{17}OH$, form films that are quite effective as inhibitors of evaporation.

Some types of molecules (hydrophylic) have an affinity for water and other types (hydrophobic) repel water. The film-forming molecules generally have a molecular structure that is composed of a hydrophylic end and a hydrophobic end. When placed on water, the hydrophylic end is attracted to the water and the other end is repelled; this causes the molecule to orient itself vertically. Hexadecanol, for example, has an hydroxyl group at the end of a long straight hydrocarbon chain hence the pencil-shaped hexadecanol molecule orients itself vertically on the water surface. The mechanics of evaporation suppression is illustrated schematically in Fig 1.

Molecule A in the interior of a liquid has, on the average, no resultant force acting on it because of attractive forces from similar molecules on all sides. Molecule A, however, is in motion and possesses kinetic energy. If molecule A were to approach the surface of the liquid, a resultant force would be exerted downward on it from the molecules below. This force causes a downward acceleration which may or may not be great enough to prevent the molecule from escaping into the vapor above the interface. Molecular activity and hence the rate at which water molecules escape from the water surface increases with temperature. In the evaporation process not only are molecules leaving the water but others are entering it from the vapor above. The rate at which molecules leave depends on the vapor pressure of the water while the rate at which they enter depends on the vapor pressure of the air above the water. Hence the rate of evaporation depends on the difference between the vapor pressure of the water and the vapor pressure of the air.

With the presence of a film it is seen that the unbalanced downward force on the water molecule B is not as great when it approaches the water surface as it had been when there was no film present. To escape out into the atmosphere, however, the water molecule B must pass between the film molecules. This requires energy and hence there is a hindrance to the passage of the water molecule through the interface. Thus evaporation is suppressed.

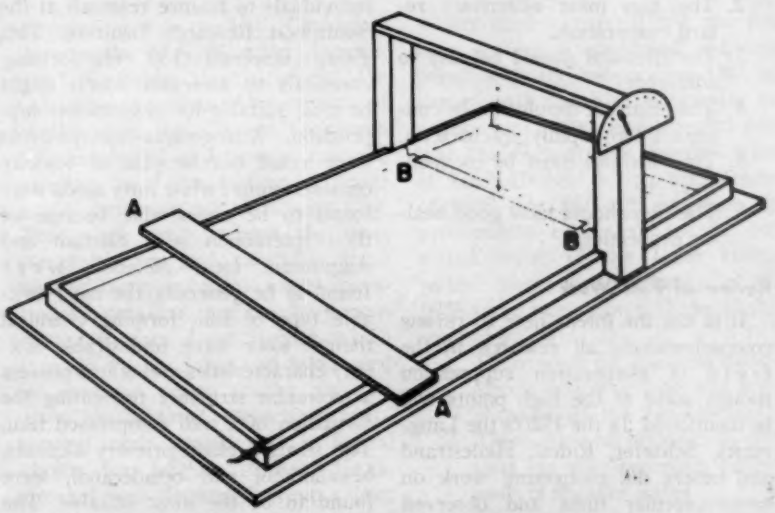


Fig. 2. A LANGMUIR TRAY for determination of film pressure.

Characteristics of the Film

A monomolecular film impedes the passage of oxygen and other gases. However, tests show that the oxygen content in reservoirs treated with film-forming chemicals has not been depressed significantly, probably because there is generally an adequate filmless area through which oxygen can pass unimpeded. This is fortunate as a reduction in the oxygen content of the water would disrupt the balance of nature and might have a deleterious effect on fish life.

When a quantity of film-forming chemical is dispensed on a water surface a film is formed immediately. This film has a thickness of less than one ten-millionth of an inch. The film generally has good spreading characteristics. Only 0.02 lb of chemical is theoretically required to form an acre of film. Tests at Stanford University showed that on a windless day a 0.10 lb dosage of powdered hexadecanol applied at a point created a film covering a 40 foot diameter circular area in less than five minutes. Within twenty minutes after application of the chemical the diameter of film coverage had increased to over 70 feet.

At a temperature of 70°F the surface tension of water is 72 dynes per centimeter. With a fully developed monomolecular film the surface tension drops to about 30 dynes per centimeter. The difference in the surface tension of water with film and without film is known as the film pressure. For a fully developed hexade-

canol film the film pressure is about 42 dynes per centimeter. Film pressures are ordinarily determined by use of a Langmuir tray, Fig 2.

Operation of this equipment is begun by filling the tray with water. Its upper edges are coated with paraffin. A measured quantity of chemical is then applied to the water surface between the barrier A-A and the boom B-B to form a film in that region. The boom B-B is attached to a torsion wire. Waxed threads extending from the ends of the boom to the walls of the tray prevent film leakage. As the barrier A-A is moved by hand toward B-B the film is compressed. Data somewhat analagous to a stress-strain test of a structural material are obtained. As barrier A-A is pushed toward B-B the position of B-B is maintained by releasing the torsion on the spring. The angle of release is measured on a circular arc. The movement of A-A is noted with the corresponding angles of release of the torsional spring. As A-A approaches B-B the film pressure increases until finally the film collapses.

Studies by electron microscope indicate that the mechanics of collapse is probably as shown in Fig 3. In the first stage of weakening some vertically oriented molecules are pushed up from the water surface until the film breaks. A double-layered ridge then rises, folds, and breaks. In the final stage the collapsed portion two molecules thick rests on the monolayer.

A plot of data from Langmuir tray tests made at Stanford University on hexadecanol films, Fig 4, show collapse occurring at a film pressure of 40 dynes per centimeter. The film pressure is determined from the angle of twist of the torsion wire while the area per molecule can be computed from a knowledge of the dosage, the molecular weight of the applied material, and the area in the tray between the boom and the moveable barrier. Fig 1 gives an indication of the flexibility of the film; i.e., as the film pressure varied from 10 to 40 dynes per centimeter the area per molecule changed from 20.2 to 18 square angstroms. The ideal film for suppressing evaporation is one whose film pressure is high; i.e., the higher the film pressure the greater the hindrance to evaporation. Hexadecanol, though an excellent evaporation retardent when fully compressed, is relatively inelastic and does not recover well once it has been compressed, decompressed, and recompressed. In other words, its healing properties are not superior. Only by supplying an excess of chemical can one be assured that a satisfactory film will be reformed after waves from wind, boats, and other disturbances have compressed portions of the film to collapse.

Another characteristic of most chemicals that form monolayers suitable for evaporation reduction is that they are consumed by certain types of bacteria such as *Psuedomonas* and *Alcaligenes*. Rates of assimilation varying from 0.03 to 0.40 lbs/day/acre have been measured in the laboratory. Another deleterious effect is that bacterial growths on the surface of discrete particles of the chemical will reduce the exposed surface and hence limit the rate of film formation.

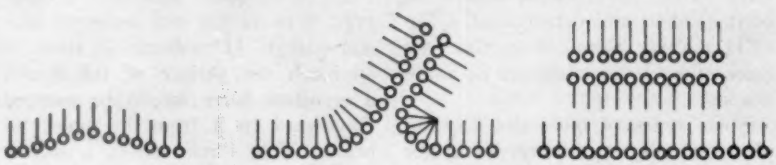


Fig. 3. THE MECHANICS of film collapse (after Ries and Kimball).

A summary of the most important characteristics of film-forming chemicals used for evaporation suppression is as follows:

1. The material must be insoluble, non-toxic, and tasteless.
2. The film must effectively retard evaporation.
3. The chemical should be easy to administer.
4. The chemical should not be consumed too rapidly by bacteria.
5. The chemical must be inexpensive.
6. The film should have good healing properties.

Review of Past Work

It is not the intent here to review comprehensively all research in the field of evaporation suppression though some of the high points will be mentioned. In the 1920's the Langmuirs, Schaefer, Rideal, Hedestrand and others did pioneering work on monomolecular films and observed that they impeded evaporation. In recent years important fundamental research on monomolecular films has been done by LaMer, Rosano, Blank, etc. LaMer, for example, found in recent laboratory investigations that a mixture of octadecanol and hexadecanol holds the greatest promise of success for practical application.

The first field studies were those of Mansfield in Australia in the early 1950's under the auspices of the Commonwealth Scientific and Industrial Research Organization. The Australians have been working continuously on the development of practical techniques for applying film-forming chemicals to open water surfaces and have made many important contributions. In 1954 Dr. Ian W. Wark of Australia spoke on evaporation suppression at a meeting of the American Chemical Society in San Antonio, Texas. Immediate interest was aroused and a group of public spirited citizens formed the Southwest Cooperative Committee on Evaporation Control. This group later incorporated as the Southwest Water Evaporation Research Council. Funds were raised from industry, municipal water districts, and private individuals to finance research at the Southwest Research Institute. This group screened 150 film-forming chemicals to ascertain which might be most suitable for evaporation suppression. Nitrogenous compounds were ruled out because of toxicity considerations; while fatty acids were found to be undesirable because of their interaction with calcium and magnesium ions. Alkanols were found to be generally the most suitable type of film forming chemical though some have undesirable toxicity characteristics and others possess a molecular structure preventing the formation of a well compressed film. The straight chain primary alcohols, hexadecanol and octadecanol, were found to be the most suitable. The Southwest Research Institute con-

ducted the first field tests in this country. The U. S. Geological Survey assisted in these tests by evaluating the reduction of evaporation from open reservoirs.

Shortly after the Southwest Research Institute commenced its work on evaporation suppression the U.S. Bureau of Reclamation entered the picture. This agency conducted numerous pan tests to screen over 100 chemicals and applied the film to several small reservoirs near Denver, Colorado. In the summer of 1958 the U.S. Bureau of Reclamation in cooperation with the U.S. Geological Survey, the U.S. Weather Bureau, the U.S. Public Health Service, the Oklahoma State Department of Health, and the City of Oklahoma City conducted an extensive research program at Lake Hefner, a water supply reservoir for Oklahoma City. This work was perhaps the most comprehensive and carefully documented testing program on evaporation suppression that has been conducted to date. Lake Hefner, which is a 2500 acre lake, had been used in previous years as the site for some fundamental research on evaporation and, hence, was a logical choice for further studies. Hexadecanol was dispensed from a boat and barge as a powder suspended mechanically in water and sprayed under pressure by pump onto the lake surface. It was found that the film was very sensitive to wind; a gentle breeze would quickly blow away the film piling it up on the far shore. During the summer of 1958 over 40,000 lbs of hexadecanol were applied to the lake. Using a method developed by G. Earl Harbeck, Jr. of the U.S. Geological Survey the reduction of evaporation was evaluated to be 9 per cent. In this method which depends on an energy budget approach combined with mass-transfer theory the evaporation that would have occurred had no film been present is computed and compared with the evaporation that occurred with the film. A careful accounting of all expenditures showed that the cost of the "saved" water at Lake Hefner during the summer of 1958 was $61 per acre-foot, approximately equivalent to the estimated value of the Lake Hefner water. Some other results of the 1958 testing program at Lake Hefner were as follows:

1. There were no apparent toxic effects resulting from the application of the hexadecanol.
2. There were no undesirable effects on the treatment processes of the lake water.
3. There was no interference with normal recreational uses of the lake.
4. There was a large increase in the bacterial content of the water though it was deemed to be insignificant.

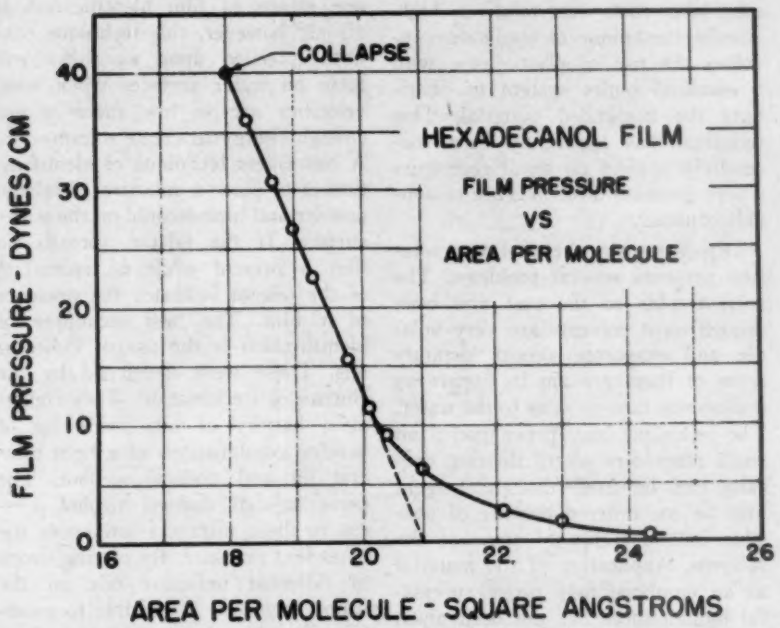


Fig. 4. RESULTS OF LANGMUIR tray test showing film pressure versus area per molecule for hexadecanol film.

During the summer of 1960 the U.S. Bureau of Reclamation, with the cooperation of the U.S. Geological Survey, the U.S. Public Health Service, the Arizona State Fish and Game Department, and the Salt River Valley Water Users' Association performed field tests at Lake Sahuaro forty miles northeast of Phoenix, Arizona. The purpose of these tests was to study the effect of the wind on the film and to develop effective means of applying and maintaining the film.

There have been several other important research programs in the field of evaporation suppression. Grundy with the East Africa Meteorological Organization in Kenya conducted extensive field tests dispensing the chemical as a solution dissolved in a petroleum distillate. W. J. Roberts with the State of Illinois Water Survey used two 3 acre reservoirs of similar characteristics, one serving as a control, the other being dosed with chemical from wire screen rafts. He noted evaporation savings ranging from 22 to 43 per cent with cost of chemicals averaging about $26 per acre-foot of saved water. During one of Roberts' tests an 8 inch rainfall occurred. It broke up the film but after the storm the film reformed from the excess chemical that was present in the water.

In recent years various personnel of the U.S. Public Health Service have made important contributions. Hexadecanol was given an unqualified toxicity clearance by the Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio. Other important research originating at the Sanitary Engineering Center includes that on the bacterial attrition of hexadecanol and the use of bactericides to counteract attrition.

Unique Problems

Many problems arise when one tries to reduce evaporation from reservoirs by chemical means. The biggest problem is wind. Even a gentle breeze will gradually move the film across the water surface. One solution to this problem is to apply the chemical almost continuously to

replace the film that has been blown away. If there is a reversal in wind direction the film will reform, particularly if there is an excess of chemical present. A partial solution to the wind problem is to select a reservoir in an area that is not excessively windy. Also it is possible that windbreaks might be useful.

Application of the Chemical. Many different techniques of administering the chemical have been tried. At ordinary temperatures hexadecanol is a white, waxy solid. It can be ground down to a fine powder or is obtainable in the form of flakes. The material can also be pelletized. Hexadecanol melts at about 130° F. A droplet of fine spray of the molten chemical will solidify to form a bead of the material. The size of the bead can be varied by changing the fineness of the spray. Hexadecanol will dissolve in certain solvents such as petroleum ether and kerosene. Several techniques of administering the chemical are as follows: from wire-screen floats, by hand as a powder or flake, as a mechanical suspension sprayed onto the water surface under pressure, as a solution dissolved in a solvent, application as an emulsion, and sprayed onto the water in a molten condition.

The use of wire-screen floats has been moderately successful on small reservoirs. To be effective, the float density should be at least one every two acres. On large reservoirs it would be totally unfeasible to have so many floats. Moreover they would interfere with boat traffic. In using the float technique the chemical within the screen may be in the form of a large solid chunk or as pellets of a size greater than the screen opening. In using floats there are the problems of screen corrosion, gumming up of the screen openings with bacterial growths, and melting of the chemical if the float is not properly insulated.

Administering the chemical by hand from a boat seems to be one of the most effective means as the chemical can be broadcast in those regions of the water surface where it is needed to replenish the film that has been blown away by the wind. This method is rather costly however because of the high labor charges. Administration by hand from shore stations is generally not effective, for widespread film coverage cannot be achieved. It is possible that the powder could be dispensed from an airplane much in the manner of a crop duster though this would be costly.

Administering the chemical as a mechanical suspension sprayed onto the water surface was the technique used by the Bureau of Reclamation at Lake Hefner in the summer of 1958. Their method involved the use of a boat equipped with a pump and pressure system so that the chemical could be sprayed onto the lake surface wherever needed. From that viewpoint it was a good method; however, labor costs were relatively high. Another technique of application involves the use of plastic pipe with a manifold outlet system to distribute the suspended material. This technique has apparently been successfully applied on small reservoirs where the wind directions are reasonably constant.

Dispensing the chemical as a solution presents several problems. The solvent adds to the cost and even though most solvents are very volatile and evaporate almost instantly some of them are apt to impart an undesirable taste or odor to the water. The technique may prove useful on small reservoirs where floating drip cans can be used though dangers may be encountered because of possible inflammability of some of the solvents. Application of the material as an emulsion may prove successful though there has not been much experience with this method.

Spraying the chemical in the molten condition holds promise as being perhaps the best method of dispensing the chemical. During the summer of 1960 this technique was used at Lake Sahuaro in Arizona and also at Stanford University. In these studies it was observed that good film coverage could not be obtained by dispensing the chemical at a single point. At Lake Sahuaro there were four molten dispensers situated at the shoreline while at Stanford there was a single molten dispenser on a float anchored away from shore. To get good film coverage the mobility of a boat is required so the chemical can be applied in those areas where it is needed. For large reservoirs the best answer to date may be the use of a boat equipped with a dispenser that ejects molten chemical as a fine spray. In all methods there are the problems of aggregation of particles and bacterial growths. These cut down the exposed area of contact between chemical and water resulting in reduced rates of film formation.

Identification of the Film. In research work and also in practical application of the films one must be able to determine whether or not a film is present. The film reduces surface tension and causes a quieting of the microwaves. Immediately after applying the chemical a slick is formed on the water surface which can readily be seen by eye. Thus one means of film identification is visual; however, this technique cannot be relied upon as slicks will form on water surfaces when wind velocities are so low there is not enough energy to create microwaves. A convenient technique of identification is to place a mixture of talcum powder and hexadecanol on the water surface. If the talcum spreads no film is present while no spreading of the talcum indicates the presence of a film. The best technique of identification is the use of indicator oils. These were developed by the Bureau of Reclamation. They consist of a battery of oils made up of varying combinations of a light mineral oil and dodecyl alcohol. The percentage of dodecyl alcohol present in these mixtures influences the spreading pressure. By placing drops of different indicator oils on the water surface it is possible to ascertain if a film is present and if so to measure the film pressure.

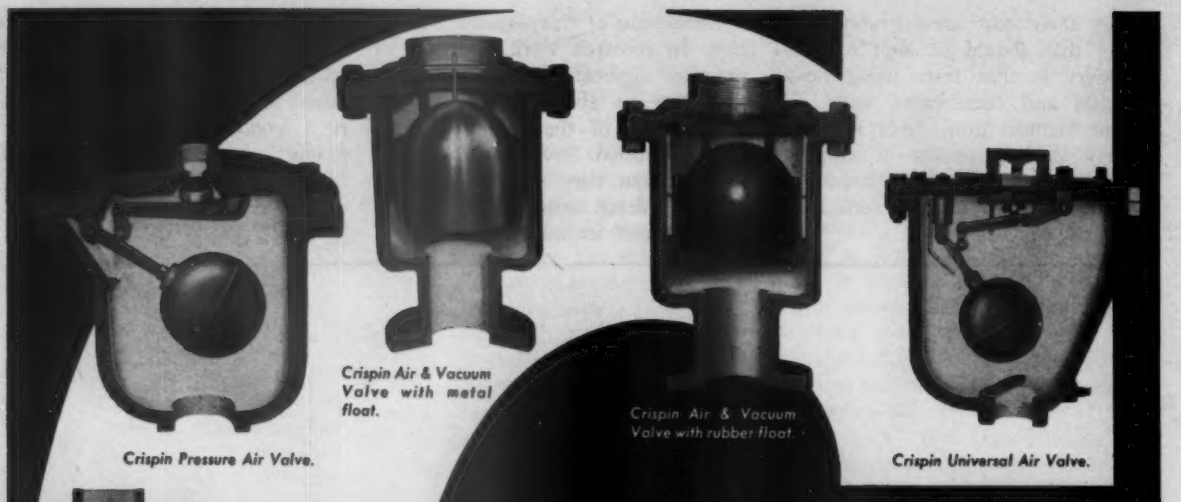
Biological Attrition. As previously mentioned the film-forming chemicals are consumed by bacteria at a rate of perhaps 0.2 lb to 0.3 lb per acre per day. To counteract this effect the use of a bactericide is indicated. Several copper compounds have proved effective though more fundamental knowledge of the action of bactericides is needed.

Cost of the Chemical. The cost of the chemical varies considerably. In small lots a good grade of hexadecanol can be purchased at 60 cents per pound. In carload lots the cost is 51.5 cents per pound. During the 1960 program at Lake Sahuaro a combination of octadecanol and hexadecanol costing 25 cents per pound was used. It is possible that new processes of manufacture and greater demand for these chemicals will

lower their cost considerably. One thing that should be kept in mind however is that tests using hexadecanol and octadecanol from different manufacturers have indicated widely varying results in evaporation reduction capabilities. Impurities apparently have a great effect on the film.

Evaluation of Evaporation Reduction. In research work and also in practical application it is important that one be able to evaluate the effectiveness of the film in reducing evaporation. Several methods are available but they will not be discussed in detail here. The techniques of evaluation include the pan coefficient approach, the use of two similar reservoirs (one with film, the other without), and the method proposed by Harbeck. The latter method is a good one though as far as practical application is concerned the instrumentation is expensive.

Editor's Note: References will appear at the end of Part II



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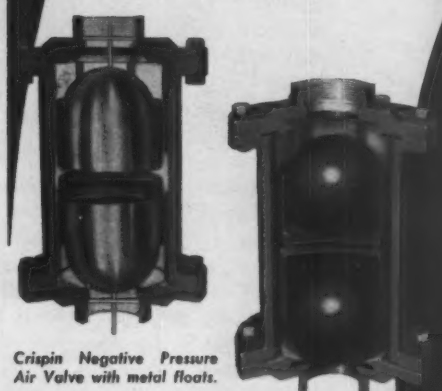

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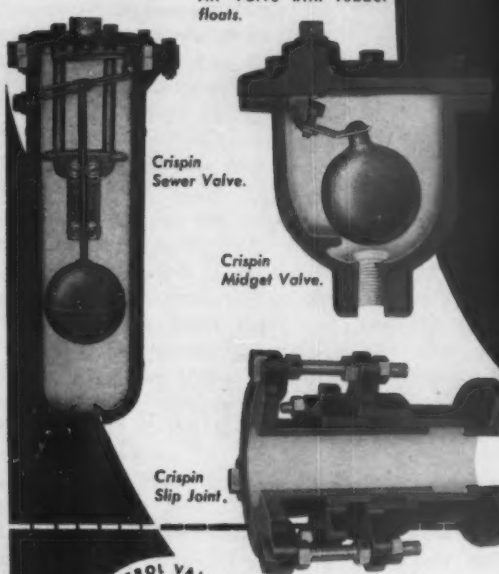

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Recent laboratory and pilot scale work is reported on . . .

Evaporation Suppression Research

Part II

by JOSEPH B. FRANZINI
Associate Professor of Civil Engr.
Stanford University
Stanford, Calif.

EDITOR'S NOTE: Continuing this evaporation suppression research, Dr. Franzini reports on the work being done to find more effective chemicals and on the application of chemicals for evaporation suppression to a pond on the Stanford campus. From this and other work, it has been possible to develop some idea of the amount of water which can be saved and its cost. It appears that reductions in evaporation in the order of 20 per cent are possible and that under ideal conditions costs will range from $20 to $35 per acre-foot.

■ DURING THE PAST TWO years research on evaporation suppression has been conducted at Stanford University under the direction of the author with the financial support of a grant from the U.S. Public Health Service. Effort has been exerted along several lines. Considerable work was done in the laboratory using the Langmuir tray in an attempt to find a chemical or combination of chemicals or an additive that could be mixed with hexadecanol to give a film with superior healing qualities while retaining proper evaporation inhibiting characteristics. This work has not yet produced any promising results.

Pan Tests

Numerous tests using evaporation pans were conducted at the University Weather Station. These are metal pans 47.5 in. in diameter and 10 in. high filled with water to a depth of 7 in. One pan filled with only water is used as control while varying dosages of different chemicals are placed on the water surfaces in the other pans. The differences in evaporation from the pans are observed over a suitable time period by adding enough water each day to keep the water levels constant. Some of the

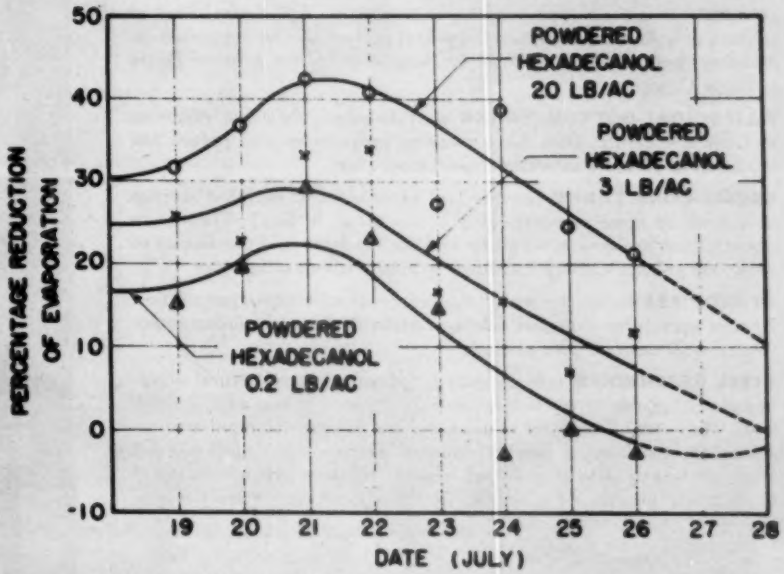

Fig. 5. RESULTS OF PAN TESTS showing the effect of varying dosage.

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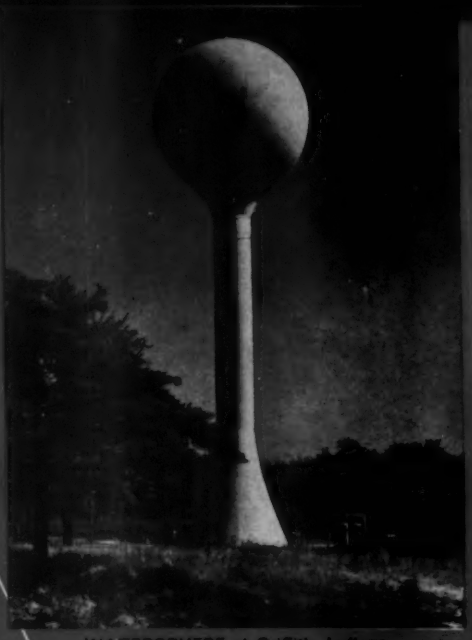
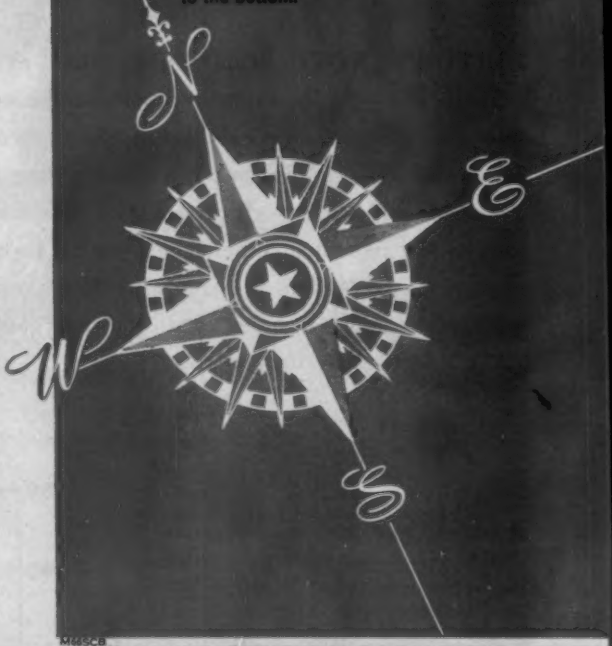


WATERSPHERE at Griffith, Indiana has 200,000-gallon capacity; is 98 ft. to the bottom.



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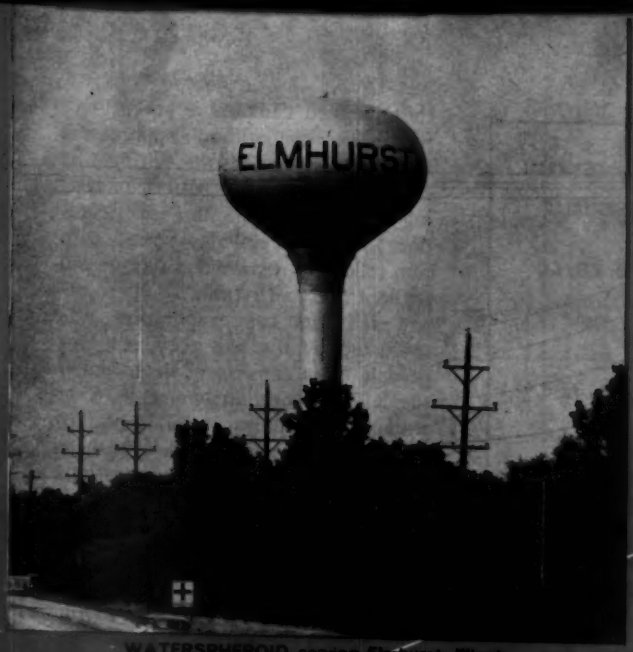
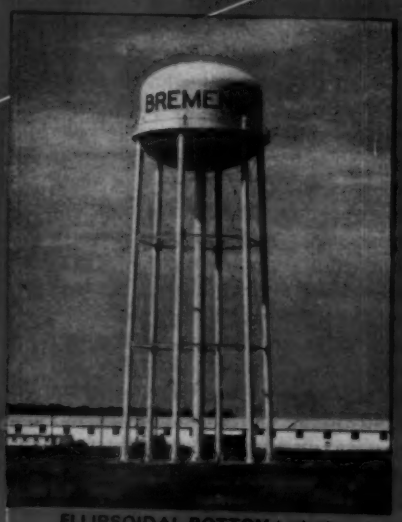


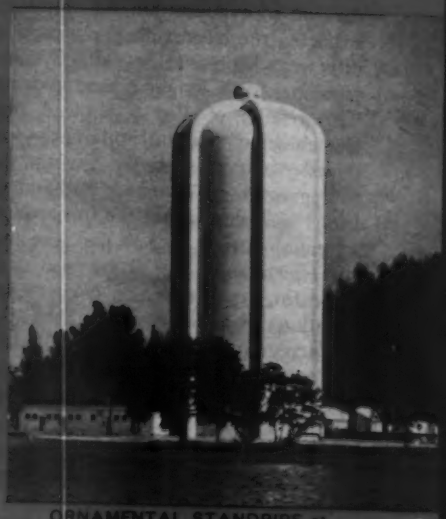
WATERSPHEROID serving Elmhurst, Illinois has 500,000-gallon capacity; is 100 ft. to bottom.

SPHEROIDAL elevated tank at Wheaton, Illinois is 130 ft. to bottom; has 1,500,000-gallon capacity.



ELLIPSOIDAL-BOTTOM tank at Bremen, Indiana has 300,000-gallon capacity.

RADIAL-CONE elevated tank at Manhattan, Kansas has capacity of 500,000 gallons.



ORNAMENTAL STANDPIPE at Clearwater, Florida has capacity of 1,000,000 gallons.

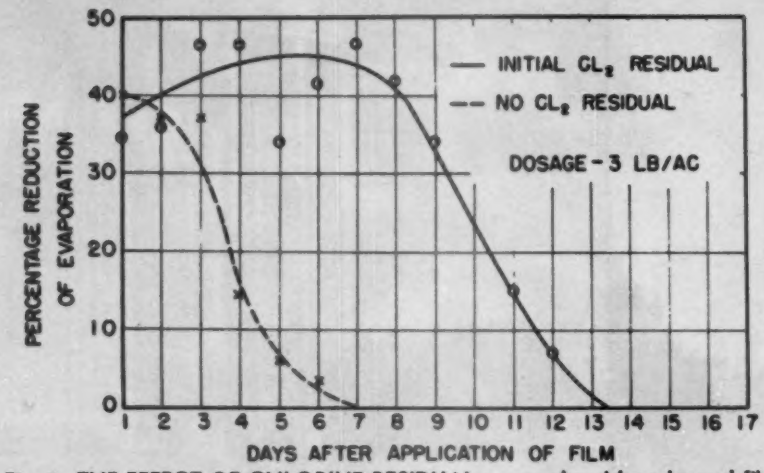


Fig. 6. THE EFFECT OF CHLORINE RESIDUAL on powdered hexadecanol film in pan tests.

results of the pan tests are shown in Figs 5, 6, and 7. Fig 5 shows the effect of varying dosages on the reduction of evaporation. As would be expected the largest dosage was most effective. Moreover its effectiveness persisted for a longer period of time. The results of Fig 6 showed that the chlorine residual apparently impeded bacterial activity giving the film greater effectiveness and longer life. Fig 7 shows that the initial hexadecanol dosage of 3 lb per acre lost its effectiveness in about six days indicating that the rate of bacterial attrition may have approached 0.5 lbs/acre/day. Applying a small dosage each day gave much better results than the application of one large initial dosage.

It is a well known fact that a monomolecular film will raise the temperature of the water surface on which it rests. Fig 8 shows some typical temperature data that were obtained from evaporation pans, one dosed with 3 lb per acre of hexadecanol and the other containing plain water. The temperatures were obtained using a multi-channel recorder connected to copper-constintan thermocouples serving as sensing elements. The water surface temperature in the pan with film exceeded that in the pan without film by as much as 7°F.

Lake Trials

At Felt Lake, a 40-acre lake on the Stanford campus, a program of full scale evaporation suppression testing was carried on during the summer of 1960. The pattern of testing was a film on, film off procedure; i.e., a several day period with film followed by a several day period without film and repeat. The percentage reduction of evaporation was evaluated by the pan coefficient approach. This consists of determining the lake evaporation by means of a water budget during periods of film and no film, and comparing them with the corresponding evaporations from a pan. This technique is open to criticism because pan coefficient, the ratio of lake evaporation to pan evaporation, is known to vary considerably throughout the year; however it is a convenient and expeditious method.

In recent years the lake had been the site of basic research on evaporation, hence there was a background of experience on the characteristics of the lake. There was enough available data to estimate seepage from the lake with a fair degree of accuracy. During the testing program there was no inflow to the lake. Outflow was measured by a recording venturi meter that had been recently calibrated and the change in lake water level was measured with a water level recorder installed in the concrete outlet tower. The relation between water surface elevation and lake surface area was available from an old survey. Since the original survey there had been very little sediment deposited in the lake as the lake is filled by the controlled diversion of water from a natural stream. Using a water budget approach the evaporation from the lake was computed. This was compared with the evaporation from a evaporation pan situated nearby on an unobstructed hill.

A tabulation of the results is shown in Table 1. It should be noted that there is an inconsistency in the results. The pan coefficient of 1.05 during the film period July 27-31 is difficult to explain. It is believed that during this period the evaporation pan was contaminated with hexadecanol and, hence, the pan readings were in error. Comparison of the pan records with pan evaporations at the Stanford Weather Station indicate the plausibility of this conjecture. Neglecting the computed pan

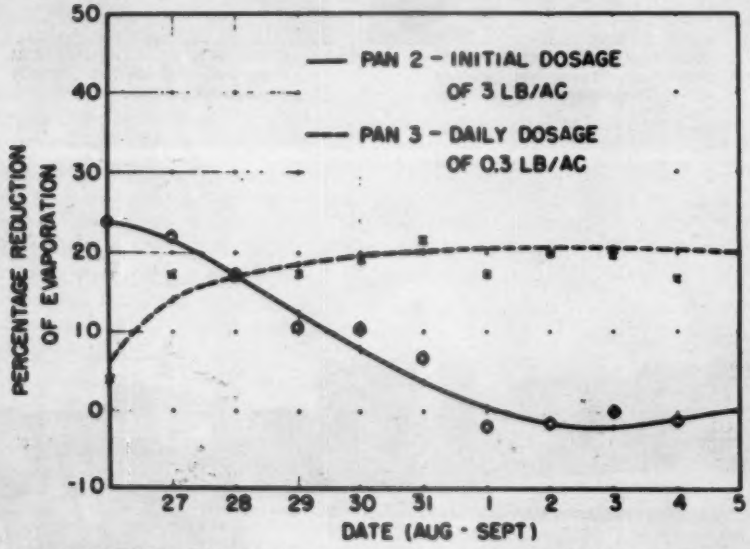


Fig. 7. PAN TEST RESULTS showing the effect of the mode of application of powdered hexadecanol.

coefficient for the questionable period gives an evaporation reduction of 23 per cent while using all computed pan coefficients results in a 19 per cent reduction.

Chemical Application

The technique of applying the chemical to Felt Lake was to dispense the powdered hexadecanol by hand from a boat. During periods of film application the operator was generally at the lake from nine o'clock in the morning to about seven in the evening. The chemical was distributed about once an hour in those areas of the lake where it was needed. The amount of hexadecanol used varied from 5 to 25 lbs per day depending on the requirements; this is equivalent to dosages ranging from about 0.15 to 0.75 lbs per acre per day. During Aug. 16-26, a windy period with a wind velocity index of 6.6 mph, the dosage averaged 0.40 lbs per acre each day while from Sept. 5-14 with a wind velocity index of 4.0 mph the average dosage was only 0.21 lb per acre per day. The wind velocity index was computed by averaging the wind velocities as measured at 10:30 AM and 4 PM by a portable anemometer situated on a raft in the middle of the lake 12 feet above the water surface. The film coverage varied but on the average was about 50 per cent during daylight hours and 95 per cent at night. There was very little wind from 8 in the evening until 10 in the morning. At 10 AM a northerly breeze generally came up necessitating the application of some hexadecanol to maintain the film. The wind usually grew stronger as the day wore on finally reaching a peak around 5 PM and then subsiding gradually to a negligible wind velocity by 8 PM.

The chief difficulty in accomplishing effective evaporation suppression is maintaining adequate film coverage on the reservoir surface. Apparently this can only be accomplished by applying the chemical continuously during windy periods to replace the film blown away by the wind.

Dispensing the chemical by hand can be an expensive operation because of the high labor costs. To reduce labor costs an attempt was made to develop a dispenser that could be set in operation and then left unattended for one or more days. Since the amount of chemical required is roughly proportional to the wind velocity it seemed logical to develop a wind-actuated dispenser. Attempts to develop a dry feed dispenser have thus far been unsuccessful because of the binding of the powdered chemical in the worm drive or other feeding mechanism. Since hexadecanol and other film-forming chemicals have a low melting point in the vicinity of 130°F it seemed that dispensing the material in the molten state might be possible. In the fall of 1959 a molten dispenser was built and tested in the Stanford University Engineering Laboratories. In the summer of 1960 this dispenser was mounted on a large raft and tested at Felt Lake. It worked reasonably well though the need of certain refinements in design were indicated. This device maintains the hexadecanol in a molten state with a butane heater equipped with a thermostat. A large anemometer-like rotor is used to drive a rotating cam which pulls a piston against a spring to admit molten hexadecanol into a small cylindrical chamber. As the cam rotates the piston is released and the spring forces a slug of molten hexadecanol into a long metal tube which terminates with a pin-hole nozzle permitting the molten material to eject into the atmosphere. The molten material is emitted as a fine spray that condenses in the air to a multitude of small particles which hit the water surface and form the film. The major problem was that with moderate winds of 2 or 3 mph not enough torque was generated to operate the mechanism. With stronger winds, even though the device operates fair-

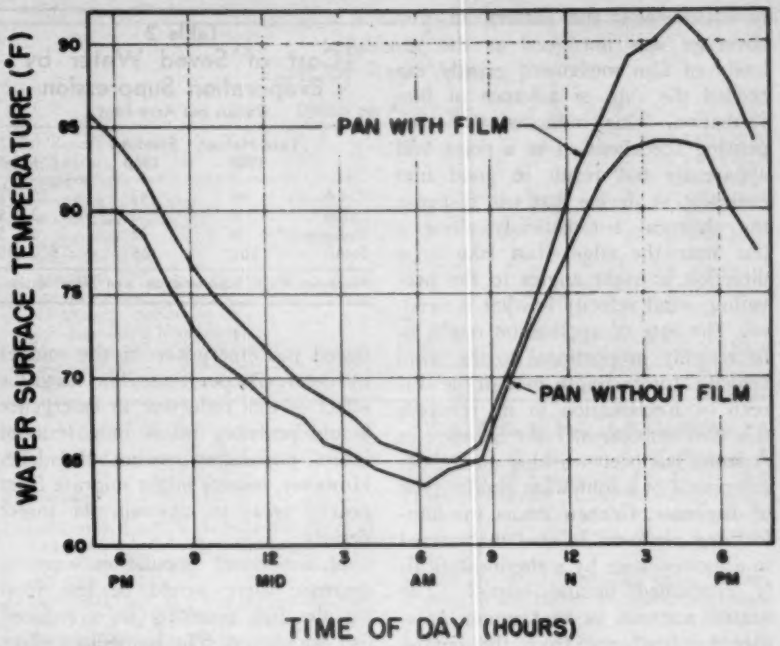


Fig. 8. THE EFFECT OF FILM on water temperature.

Table I

Date	Condition	Average Pan Coefficient During Period	No. of Days
July 7-11	No Film	0.69	5
12-20	Film	0.47	9
21-26	No Film	0.82	6
27-31	Film	1.05	5
Aug. 1-15	No Film	0.93	15
16-26	Film	0.88	11
27- 4	No Film	1.21	9
Sept. 5-14	Film	0.90	10
15-23	No Film	1.16	9

ly satisfactory, the pattern of film coverage was not good as the velocity of film movement greatly exceeded the rate of advance of film formation. This indicates that dispensing the chemical at a point will apparently not result in good film coverage. A device that will dispense the chemical automatically along a line near the edge of a lake in a direction at right angles to the prevailing wind velocity is what is needed. The rate of application ought to be roughly proportional to the wind velocity. Interestingly enough the Bureau of Reclamation in its research this past summer at Lake Sahuaro in Arizona has been working on the development of a somewhat similar type of dispenser. In their device the film-forming chemical is also maintained in a molten state by a thermostatically controlled butane burner. The heated material is kept under pressure by surcharge from the butane fuel tank. A small anemometer actuates an electronic relay which operates a release valve permitting emission of the molten material through a fine nozzle. This happens when the wind velocity reaches a certain level. The relay system is designed to cut off when the wind velocity exceeds 20 mph. At such a velocity application of the chemical is useless as the film is blown away much too quickly to do any good.

Effects on Insects

In connection with the work at Felt Lake data were gathered on the effect of the film on the emergence of insects from the lake. Four insect traps, were set in the lake. These were constructed of plexiglass in the shape of a cone and attached to a cork ring for flotation. A collecting bottle was placed in the inverted position over the upper opening of the trap to catch the emerging insects. Four traps were used: the water within two of the traps was free of film while a hexadecanol film was maintained on the water surface in the other two traps. During the test period the collecting bottles were replaced twice a day, at 6 AM and 6 PM. The insects that had been trapped were taken to the laboratory, identified, and counted. The Tendipedidae, midge, was the most common insect and was used as the basis for data. A statistical analysis of the count showed that the film had reduced the emergence of the midges by nearly 70 per cent. The longtime effect of this reduction in emergence would probably result in a reduced insect population within the lake. However, insects might migrate from nearby areas to maintain the insect density.

If the insect population were to decrease there would be less food for the fish resulting in a reduced fish population. The immediate effect of the decrease in insect emergence however as indicated by inspection of fish stomachs was that those caught during film application contained more insects than those caught during periods when the film was not applied. Not enough data were gathered however for conclusive results.

Because of innumerable variables and other factors no definite conclusions can be drawn at this time on the long time effect of a film on the fish.

Table 2
Cost of Saved Water by Evaporation Suppression
Dollars per Acre Foot

	Lake Hefner, 1958	Stanford 1960	Ideal
Chemicals	46	43	15 - 25
Labor	6	110	3 - 5
Equipment*	9	12	2 - 5
Total	$61	165	$20 - 35

*Includes Fuel, Maintenance, and Depreciation.

Cost of Evaporation Suppression

Various investigators have quoted the cost of conserving water by reducing evaporation through the use of monomolecular films. Costs as low as $6 per acre foot have been mentioned; however these seem to be entirely unrealistic. Table 2 gives some representative cost figures.

It is interesting to note that the cost of chemicals in the Lake Hefner tests of 1958 and those at Stanford in 1960 were almost identical. At Lake Hefner the hexadecanol was purchased in carload lots at 51.5 cents per pound while that used at Stanford purchased by the barrel cost 60 cents per pound. Even though the cost of chemical was higher at Stanford, the cost of chemical per unit of saved water was slightly lower. An explanation of this reversal is that at Stanford a considerably greater percentage of a real film coverage was achieved as the Stanford lake, 40 acres, was much smaller than Lake Hefner, 2500 acres. As the demand for film-forming chemicals increases and the techniques of manufacture improve, the cost of chemical will drop. At Lake Sahuaro in Arizona in the summer of 1960 the chemical, a mixture of octadecanol and hexadecanol, was purchased for 25 cents per pound. Hence a chemical cost of $15 to $25 per acre foot of saved water seems reasonable today. In future years this cost may decrease sizeably.

A comparison of the labor costs at Lake Hefner and Stanford requires explanation. The technique of dispensing the chemical at Stanford by boat was not an economic one for such a small lake. Actually the boat operator spent the majority of his time making limnological and meteorological observations in connection with the research program. However, all of his time was charged against labor for dispensing the chemical as he would have to have been on duty at the lake all day to accomplish this job properly. If he were only dispensing chemical he could have serviced a lake many times larger than the Stanford lake.

A labor charge as low as $3 to $5 per acre foot of saved water appears to be easily within reach under ideal conditions. These conditions imply a reservoir of optimum size, perhaps 1000 to 2000 acres per boat and operator. The reservoir should have a minimum of inlets and coves. It should be located in an area of high evaporation and the winds should be moderate. Small reservoirs, less than 100 acres, can perhaps be most economically dosed by use of floats, while intermediate sized reservoirs, 100 to 1000 acres, might, under proper conditions, be dosed effectively with automatic dispensers. Under good conditions the cost of equipment including fuel, maintenance and depreciation could be as low as $5 per acre foot of saved water and under optimum conditions as low as $2 per acre foot. The film method will not work well on very large reservoirs because the long reaches permit the formation of large waves that break up the film.

It is entirely possible to save water by the application of monomolecular films on reservoirs at a cost ranging from $20 to $35 per acre foot.

It should be kept in mind however that these cost figures apply only to selected reservoirs, those of proper size and shape in areas of moderate wind and high evaporation.

What of the Future

It appears that evaporation suppression by chemical means may shortly become an accepted method of conserving water in certain areas. A comparison with the costs of alternate sources of water (Table 3) shows the monomolecular film method to be competitive.

It should be borne in mind that the film method will not produce great quantities of water. Before resorting to the method careful advance study is in order to ascertain the probable cost of the saved water. This cost should then be compared with costs of alternate sources of water before a decision is made to apply the method. Much research and developmental work remains to be done before the full potentialities of the method are realized.

Table 3
Cost of Raw Water

	Dollars per Acre Foot
Local Runoff	$ 3.00 - 10.00
Groundwater	$ 3.00 - 10.00
Imported Water	Variable
Reclaimed Waste Water	$25.00 - 40.00
Sea Water Conversion	
Distillation	$ 250 - 600
Solar Stills	$ 350
Freezing	$ 700
Ion Exchange	$8,000*
Electrolytic Action	$ 500*
Ion-Permeable Membranes	$3,000*
Evaporation Suppression	$20.00 - 35.00

*Considerably lower for brackish water

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Toxicity Studies

on Cadmium and Hexavalent Chromium

. . . in Concentrations Which May Be Expected in Public Water Supplies

By RASHID A. ANWAR, CARL A. HOPPERT
and RICHARD U. BYERRUM
The Kedzie Chemical Laboratory
Michigan State University
East Lansing, Michigan

RESUME: Toxicity of Cadmium and Hexavalent Chromium has been under study for about five years. Of particular concern are the small amounts probably present in public water supplies. Results to date of four year studies are reported here.

■ EXPERIMENTS to study the effect of prolonged ingestion of small quantities of cadmium and hexavalent chromium in the drinking water of rats and dogs have been in progress in our laboratory for approximately five years. These studies seemed pertinent because cadmium and hexavalent chromium have occurred in water used for human consumption in various parts of the world, largely through contamination by industrial wastes. Although the acute toxicity of these substances has been studied previously, no experiments to determine the effect of small quantities of cadmium and hexavalent chromium in concentrations which are occurring in drinking water have been made. It is hoped that the results of these studies will be useful in establishing a safe concentration of these substances for human consumption in the drinking water.

Cadmium.—An initial study with rats involved the feeding of cadmium for the period of one year. Separate groups of male and female rats of the Sprague-Dawley strain were given, *ad libitum*, distilled water containing 0.1, 0.5, 2.5, 5 and 10 parts per million (ppm) of cadmium (in the form of $CdCl_2$). Control animals were administered distilled water. All other conditions were the same for all the animals[1]. Some of the rats were sacrificed at the end of six months and the rest at the end of the year. During the period of this study no noticeable differences between the experimental groups and the control group were observed in water intake, food consumption or body weight. Nor did examination of blood and other tissues for pathological changes show any differences among the various groups and the control group. However, although no pathological changes were noted, the cadmium content of liver and kidney was found to increase in direct proportion to the concentration ingested. The tissue concentrations observed at the end of one year were roughly twice those seen at the end of six months.

Additional information on the absorption and distribution of cadmium in rats was gained by using radioactive cadmium (Cd^{115})[2]. Cd^{115} was administered both orally and intravenously to young adult male rats and, in both cases, practically all of the absorbed cadmium was found to be concentrated in liver and kidney. The quantity of cadmium, expressed as microgram per gm. wet weight of tissue, was higher in kidney than in liver, although the total quantity was greater in liver due to its larger weight. No cadmium could be detected in the urine throughout the course of this experiment (5 weeks). It was also observed that once cadmium gets into the liver and kidney, it stays there for relatively long periods of time.

Studies with Cd^{115} in the dog[3] showed that certain proteins in the liver have a greater affinity for cadmium than others; and these substances may therefore be a part of a detoxification mechanism whereby cadmium is removed from circulation so that it may not inhibit enzymes, especially enzymes containing sulfhydryl groups. The presence of such

cadmium-binding proteins may account for a certain amount of tolerance for this element.

In another experiment, dogs were given, *ad libitum*, drinking water containing 0.5, 2.5, 5.0 and 10 ppm cadmium (as $CdCl_2$), for four years and were sacrificed at the end of that period. There was a progressive increase in liver and kidney concentration of cadmium with the increase in concentration of cadmium in the drinking water [4]. However, the tissue concentrations in dogs receiving 10 ppm of cadmium were about the same as in dogs receiving 5 ppm. Some pathological changes have been observed microscopically in the kidneys and livers of dogs receiving 10 ppm of cadmium. The details of these observations will be published later.

The results of the various experiments carried out to date indicate that in the course of time cadmium accumulates in the liver and kidney tissue of animals, even when given in very small concentrations. This finding would suggest that prolonged ingestion of cadmium, even in small quantities, may lead to harmful effects, and in fact some pathological changes have been noted in dog liver and kidney after ingestion of water containing 10 ppm. Fortunately, cadmium carbonate is insoluble in both cold and hot water and as the normal water supply is usually quite rich in carbonate, cadmium when present in small concentrations should precipitate out and, therefore, be eliminated at the processing stage.

Chromium.—In order to determine the effect of ingestion of small quantities of hexavalent chromium in rats, males and females of the Sprague-Dawley strain were given, *ad libitum*, distilled water containing 1, 5, 10, 15, and 25 ppm chromate (as K_2CrO_4) [5]. Some of the animals were sacrificed at the end of six months and the rest at the end of one year. No toxic symptoms were observed in any of the groups during the course of this experiment. Microscopic examination of tissues did not show any significant pathological changes in any of the experimental groups. Analysis of tissues to determine the chromium concentration, showed that animals receiving approximately 8 ppm of CrO_4 or below, could excrete most of the chromate taken in [6]. But tissue retention was much higher when concentrations greater than 8 ppm were fed in the drinking water.

Absorption and distribution of chromium in the rat was further studied using radio-chromium (Cr^{51}) [7]. A single, orally administered solution containing 57 micrograms of chromium as $Na_2Cr^{51}O_4$ was absorbed to the extent of about 6% in fasted rats and about 3% non-fasted rats, as judged by the excretion of the administered chromium in urine. Hexavalent chromium was absorbed to a much greater extent than was trivalent chromium. Considerable reduction of chromate to the trivalent state occurred in the stomach and to a lesser extent in the intestine. Maximum content of radioactive chromium one day after administration of this material, occurred in the liver (about 1% of the total dose). All tissues studied, with the exception of spleen, showed a decreasing concentration of chromium with time.

Long term studies in which hexavalent chromium was fed to dogs were also carried out. Separate groups of dogs were given, *ad libitum*, drinking water containing 1, 5, 10, 15 and 25 ppm of chromate (as K_2CrO_4). The dogs were maintained on this regimen for four years and were sacrificed at the end of this period. The results of tissue analysis for total chromium showed that chromium concentration was higher in liver than in kidney or spleen [4]. The concentration of chromium in liver, kidney, and spleen was low and approximately the same in dogs getting chromate at all levels up to 15 ppm. There was an appreciable increase of chromium concentration in the liver of dogs getting 25 ppm of chromate. Examination of blood and other tissues for pathological changes revealed none at any of the levels of hexavalent chromium administered.

An interesting finding in both a one and two-year study in which chromate was fed to rats at different concentrations in the drinking water was that the rats receiving chromium had greater longevity than the controls. The reason for this fact was not immediately apparent.

Recently Schwarz and Mertz have shown that chromium is a glucose-tolerance factor in rats and may, therefore, be considered a physiological element [8]. In the light of our work and this recent finding, it would appear that chromate in low concentration has no deleterious effects upon rats and in fact may be necessary for proper functioning.

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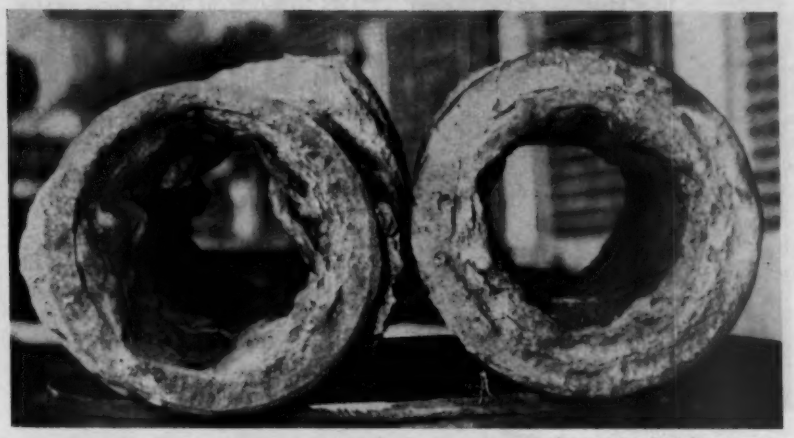

Courtesy Ace Pipe Cleaning, Inc.

FIG. 1. ACCUMULATED deposits shown in these pipe sections were as much as 2 inches thick.

by PHIL HIRSCH,
Chicago, Ill.

EDITOR'S NOTE: Many cities faced with increased demands for water look at tired old mains and question—replace or rehabilitate? Generally the size of the mains and feeder lines are adequate but their capacities have been restricted by deposits or tuberculation within the pipe. In many instances, such as reported in this article, cleaning has increased capacities of water distribution lines to meet requirements.

■ WATERMAIN CLEANING was undertaken by Murphysboro, Ill., for the first time. The mains had been in service for over 65 years and deposits as much as two inches thick had reduced the original inside diameter of piping by one-third of their capacity.

The city of some 11,000 population was expanding and had to increase capacity of its water distribution system. Either new mains had to be installed or the existing network cleaned. Cleaning was decided to be the best solution because flow could be increased through the existing distribution system to meet present demands as well as anticipated future requirements. Cleaning could be accomplished for a fraction of the cost necessary to install new mains.

Residents obtaining water from about half of the Murphysboro water distribution system were seriously short of supplies and often during peak demand periods were completely without water. Mr. Fraley, distribution superintendent, said that in some areas on many of the hydrants, "you could stop all water from coming out simply by putting your hand against the opening."

This affected area consisted of approximately 77,000 ft. of 4 and 6 inch mains and feeder lines. Accumulated deposits illustrated by pipe sections in Figure 1 restricted flow to the area at least 20 per cent. These pipes had deposits as much as 2 inches thick which reduced the carrying capacity one-third.

The Big Muddy River is the source of supply for the city. The raw water contains a relatively high percentage of manganese, the removal of which has been assisted through the construction of Crab Orchard Lake. This lake was built by the U.S. Corps of Engineers in 1940 and is reported as the largest man-made body of fresh water in the world. The headwaters of the Big Muddy flow into this lake allowing for some pre-precipitation of manganese.

New mains installed since construction of this lake have not been seriously affected by deposits restricting their capacity. Pumpage to the city distribution systems ranges from a minimum of 0.3 to a maximum of 0.8 mgd with the average near 0.5 mgd. Three electrically driven pumps having a total rated capacity of 1400 gpm supply the city through 10 and 12 inch mains. One 150,000 gal, elevated storage tank is located on the system which assists in meeting peak demands and maintaining pressure.

Cleaning Devices

Two devices were employed in cleaning deposits from old mains on

the system. They were a chain-head auger and a scraper-type cleaning tool.

The chain-head auger is essentially a steel rod which has short lengths of chain attached to it. On the end of each chain is a heavy metal weight. The steel rod is rotated at speeds between 300 and 1,000 rpm and the weights, swung out by centrifugal force, beat against the pipe knocking off the deposits. Power is supplied by a 25 h.p. truck-mounted motor equipped with a reel of flexible steel line 3,000 ft. long. This arrangement provides for simultaneous pushing and rotating the auger through the pipe sections.

The scraper type tool consists of several discs strung on a flexible steel rod and anchored front and back. Extending from the circular edge of the discs are rectangular spring steel scrapers bent at the ends (see Figure 2). This tool is pulled through the pipe sections by a power winch.

The chain-head auger is used in those pipes containing hard mineral deposits and the scraper-type tool is designed to remove incrustations or tubercles.

Courtesy Ace Pipe Cleaning, Inc.

FIG. 2. SCRAPER TYPE TOOL of several steel discs strung on flexible steel rod and anchored at both ends.

Preparation for Cleaning

Either tool can be used to clean pipe sections up to 3,000 ft. in length. They cannot negotiate bends greater than 45 degrees.

Pits are dug at both ends of the pipe section to be cleaned. These pits are usually 4 by 6 ft. wide and dug to a depth of one foot below the pipe. A power saw is used to remove 3 ft. lengths of the pipe exposed in the pits.

Pipe Cleaning

When using the scraper-type tool, the tool is inserted in the upstream end and the pipe section is joined again to the pressure main with Dresser couplings. The valve is opened and the tool is pushed by the force of water and pulled by the towline through the section to be cleaned.

In using the chain-head auger the tool is pushed through the section and removed, then water is released into the section to flush out debris.

A portable pump is used in both instances to remove water and debris from the downstream pit. A fire hose is generally used to convey the discharge from this pump to a nearby storm drain. Any accumulation of solids remaining in the pit are shoveled out.

All "T's", elbows, and similar appurtenances were cleaned manually.

Courtesy Ace Pipe Cleaning, Inc.

FIG. 3. POWER SAW cuts section from upstream end of water main so that cleaning tool can be inserted into pipe.

Summary

The Murphysboro personnel performed all pit excavation and backfilling with their own equipment. They inspected and replaced defective units, such as valves, in each section being cleaned. Pipe-runs averaged 800 ft.

The total costs for the entire cleaning operation came to approximately $34,000. This expenditure provided increased flow to outlying areas, improved hydrant capacities, and eliminated shortages in previously troubled areas. It is hopefully anticipated that the National Board of Fire Underwriters will re-evaluate the Murphysboro classification and place the homeowners in a lower rate category. This would be an added tangible return from the expenditure of city funds for cleaning water mains.

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Application of Fluorides to Water*

by WILLIAM T. INGRAM
Adjunct Prof.,
New York University,
College of Engr.
New York, New York

■ AMONG THE QUESTIONS often raised with respect to water fluoridation is the one concerning the cost of installation, maintenance and operation of fluoridation units. The author has made extensive studies of fluoridation practices in twenty major cities of the United States[1] and has accumulated additional data that may be helpful to engineers, water plant superintendents, and others who may find it necessary to make estimates of water fluoridation costs and to plan for the application of fluorides to water.

Treatment Practices

Application systems for fluoride bearing chemicals vary in detail according to the layout of treatment units and water plant design. In some plants it was necessary to build additional space to add application equipment or to provide storage for chemical. In others it was only necessary to make minor alterations to provide all required space. Cities such as Denver, Colo., Indianapolis, Ind., Milwaukee, Wis., Pittsburgh, Pa., Providence, R.I., and San Jaun, Puerto Rico, have used sodium silicofluoride successfully. Others such as Charlotte, N. C., and Norfolk, Va., have used sodium fluoride. St. Paul, Minn., has used both and in 1957 changed to hydrofluosilicic acid.

Dry Chemical Application Systems

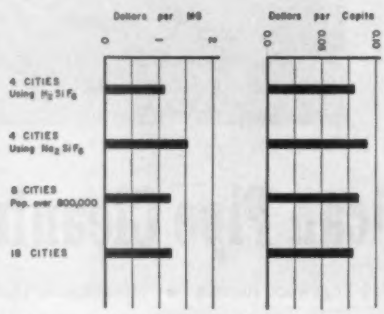
The essential components of application systems for dry chemicals such as sodium silicofluoride (Na_2SiF_6 include:

1. Means of delivery by truck or rail.
2. Dry storage space.
3. Provision for moving chemical from storage to charging hopper.
4. Hoppers for feed supply.
5. Measuring and proportioning equipment equipped with chemical feed regulation, overload protection and alarms.
6. Recording charts to record time of operation, weight and other operating data.
7. Regulation of water flow to solution tank.
8. Mixing and solution tank.
9. Transfer line for chemical solution to point of discharge.
10. Discharge pipe placed to obtain good mixing of chemical solution with water flow.

Large plants may find it convenient and more economical to have dry chemical delivered in either bulk or in bags or drums. The material is then transferred to storage bins by a pneumatic transfer system under negative pressure to avoid dust. It is essential that no dust be allowed in the general atmosphere of the treatment plant. Normally, bags are placed on pallets which can be transferred by fork lift truck to storage. In smaller plants, the transfer may be accomplished by hand on transfer dolleys. Larger plants keep from 40 to 125 tons of material available in storage while the small plants can be well supplied with 10 to 15 tons storage. While actual storage need is dependent on the relative ease of replacement and proximity of the source of the chemical, it is desirable to have approximately three months supply within easy reach of the plant.

Each feeder unit must have a storage hopper which can feed chemical to it by gravity. Although the chemical storage facilities used for other chemicals have been converted to fluoride chemical storage, the feed storage need not be larger than one day's supply. The hoppers are usually filled once each day.

The top of the hopper is of closed construction with a self-closing charging door. A local exhaust ventilating system equipped with dust removal equipment is connected to the top of the hopper so there is no excessive dust discharge either around the hopper or to the outside atmosphere. Workmen wear gloves and dust respirator masks while transferring chemical from bags or drums to the charging hopper.



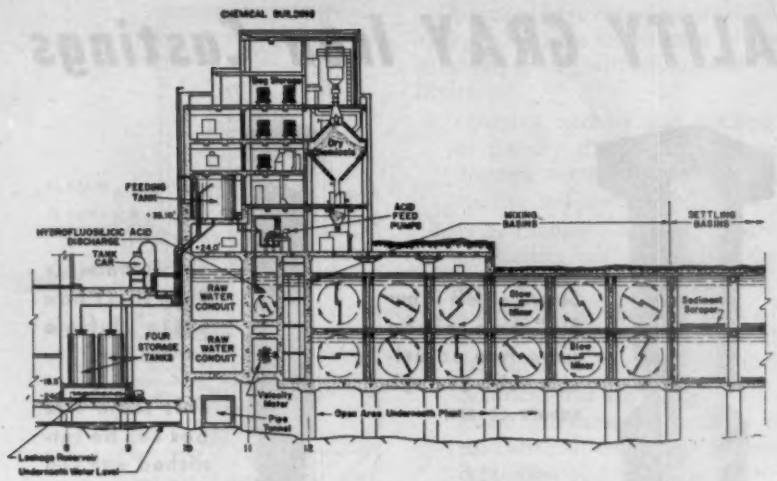
NEW YORK UNIVERSITY water fluoridation study.

Weighing and measuring units are of two types. Both are available from commercial manufacturers. The weighing type is constructed in such a way that material is fed to a belt which either vibrates or moves the material fed to it onto the solution tank. With the material weighed as it feeds, the actual quantity fed over a given period of time can be accurately checked. Dosage or feed rate can be set by a scale calibrated to the chemical in use. A change in balance activates adjusting devices regulating the amount of material fed, thus avoiding both over and under dosage. Alarms signal defective operations, and some machines are equipped with cutout relays which stop the flow of chemical entirely if the feed chute is flooding.

The volumetric type is suitable for small installations. A hopper supplies material to a feeding orifice which can be adjusted to the desired dosage rate. The unit is mounted on a scale permitting any loss in weight to be recorded.

Both sodium fluoride (NaF) and sodium silicofluoride (Na_2SiF_6) must be put into solution. Hence, the mixing and solution tank is equipped with a water flow such that the desired F ion content will be obtained. Sodium fluoride has a solubility of 4 per cent at 60° F while sodium silicofluoride solubility is approximately 0.4 per cent at 75° F. Furthermore, 19.3 lbs of NaF in 58 gallons of water, when applied to one million gallons of water, will produce a content of 1 mg/l and 14 lb of Na_2SiF_6 in 335 gallons of water will produce the same dosage when applied in one million gallons of water. Care must be taken to prevent the precipitation of calcium fluoride (CaF) as a

*Prepared in September 1960 for publication in "Water and Sewage Works".



SECTIONAL ELEVATION of hydrofluosilicic acid system.

crustation, in the solution tank and pipe lines leading to the point of application. Weaker solutions do not precipitate CaF, hence it is suggested that units be designed and operated using three to four times the required amount of water for saturation. At least 9.3 gallons per pound of NaF and 76 gallons or more per pound of Na_2SiF_6 should be used. This quantity may be cut back on an experimental basis to determine a lesser volume that could be used without precipitation of CaF in any specific water.

Plastic pipe offers the least trouble in carrying fluoride solution to the point of application. Many plants have used polyvinyl chloride pipes successfully. Restrictions at the discharge point are to be avoided. It has been the experience at many plants that nozzles and diffusers could be removed without causing any difficulty in obtaining complete mixing and a satisfactory level of F ion in the water.

Liquid Chemical Application Systems

The most widely used liquid application of fluoride bearing chemical is one using hydrofluosilicic acid (H_2SiF_6). Large cities such as Chicago, Philadelphia, Baltimore and St. Louis have used acid successfully.

Components of the system for liquid application are not greatly different than those for dry chemical application. Tanks are provided for storage. Concentrated acid, 24 per cent F or greater, is placed under air pressure or drained by gravity from tank cars or tank trucks into storage tanks at treatment plants. The size of storage tanks is, as in dry chemical storage, dependent on the availability and shipping distance of supply. Baltimore, with its source within trucking distance, provides less than 12,000 gallons total storage for its two plants. Chicago has nearly 740,000 gallons storage capacity distributed among three plants.

Small supply tanks are used ahead of some form of positive action pump. Pumps are built with plastic heads with diaphragm or piston action, and no acid can bypass the pump. Hence, when the pump is not working there is no feed. Pumps can be regulated to feed the required amount of acid. At 23.75 per cent acid concentration, 3.34 gallons applied per million gal- feed pumps of the positive feed type lons of water will produce a concentration of 1 mg/l F ion. Chemical are available from a number of manufacturers.

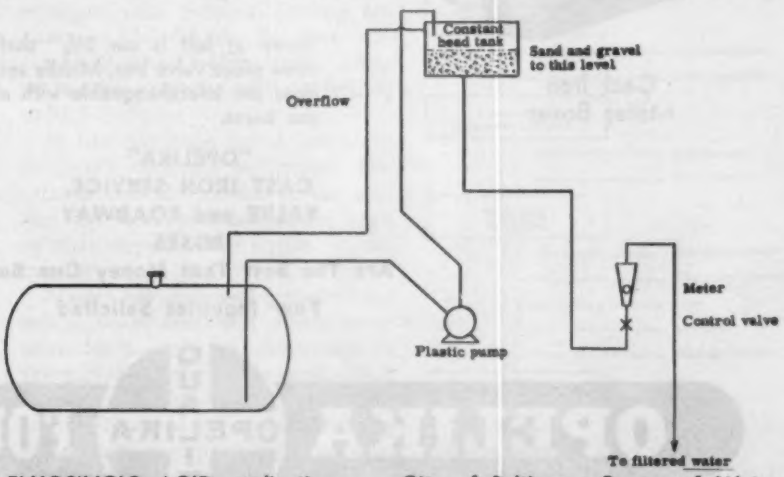
Records of the amount of chemical fed can be kept accurately by gauge readings on tanks. Pumps can be calibrated accurately. Meters are also used following a constant head tank. A continuous flow of acid is pumped to the tank with an overflow return. A variant on this is to remove a known volume from the head tank by dipping at predetermined speed. In such installations, the acid is diluted to a lesser concentration (18 per cent F^- at Chicago).

Dry Feed

Omega GLW-O	W & T 378041
Omega GLW-ORL	W & T XA107041
Omega Volumetric Model 50A	W & T A417
Omega 51F	Infilco Volumetric Converted Soda Ash Feeder
W & T Merchen Type WB9LMG	Converted Activated Carbon Feeder
W & T A635	

Liquid Feed

Proportioneers Model 2-47
Vanton Type XB
Milton-Roy Displacement
Hills McCanna Model UM-2F
Omega Rotodip Model 65



FLUOSILICIC ACID application — City of Baltimore, Bureau of Water Supply, Purification Division.

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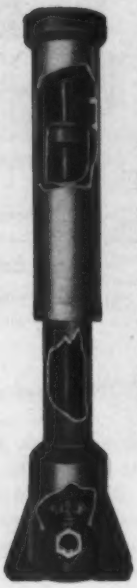

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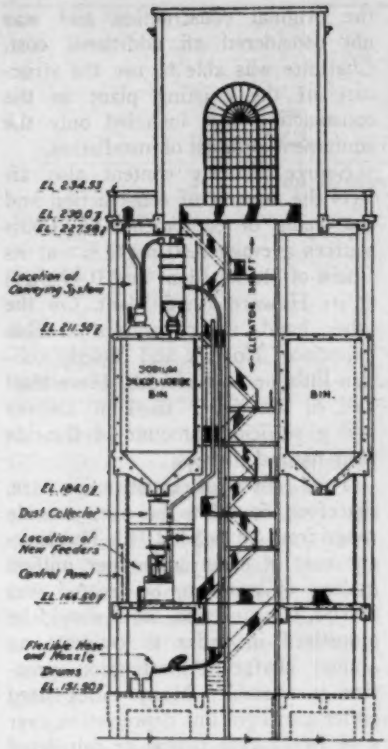


FLUORIDE INSTALLATION, tower section, Washington, D. C. water system.

Feeder Equipment

During the studies previously mentioned, the author obtained information on feeder equipment used for fluoride chemical application in thirty water systems. The following provides information on different types of equipment in use at the time of the studies.

Chemical is required to meet Standards of the American Water Works Association[2, 3, 4]. Money is saved by letting annual or longer contracts. The appropriate specification is normally incorporated in the contract specifications.

Operating Problems

Problems of handling fluorides are not materially different than those of handling other water treatment chemicals. The usual precautions need to be taken to keep equipment in order and properly maintained. Protection against dust is probably less of a problem since the material quantities handled are not as great. Local exhaust ventilation combined with care in emptying sacks or drums into charging hoppers, plus good housekeeping, provides adequate dust control.

Operators have experienced the following and have taken care of the situations arising without unusual difficulty.

1. Clogging, arching and blocking of the dry chemical in storage hoppers occurs if the salt is too fine and powdery.
2. Over-running to the feeder mechanism will occur when the material is too free flowing.
3. Dampness in the chemical causes balling and the material may arch and block the chute.
4. Solutions that are too near saturation will cause encrustation in the chemical feed pipe and cause deposition of precipitated materials at the openings of diffusion or dispersion tubes.

When a source of supply is changed, it is desirable to make careful observation of its handling behavior and to make minor adjustments to control flow.

Daily laboratory control checks, weight checks, and other usual plant control procedures apply to the process of fluoridation as they do to the handling of other chemicals.

From the above discussion of treatment practice, it can be observed that the installation of water fluoridation treatment is usually quite feasible and not inconsistent with the installation of other types of treatment. The only type system that presents special problems is one having many individual and isolated wells or surface sources as a source of supply. Each source leading directly to the distribution system must have a feeder unit. San Juan, Puerto Rico, has 59 fluoridation stations, each equipped with chemical feeding apparatus. Philadelphia has five stations with seven feeding units. Chicago has three stations with six feeding units.

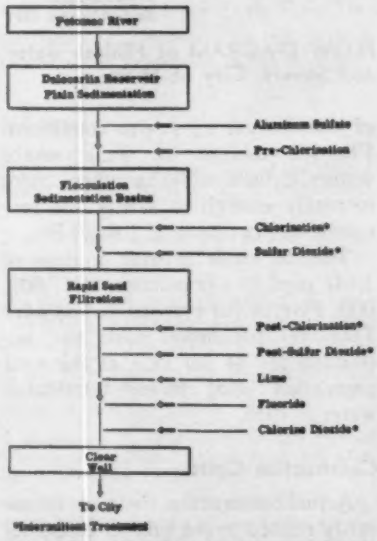
It has not been found necessary to install duplicate equipment. Decreased fluoride content in the system for short periods of time, such as that required for repair, is not critical.

Maier[5] has described a method for use at water treatment plants using alum for flocculation. Advantage is taken of the fact that fluorspar, (least expensive of the sources of F ion), can be dissolved in solution containing aluminum sulphate in direct proportion to the strength of the alum. A 10 per cent solution of alum will produce 1 per cent fluoride. It requires approximately two hours at room temperature to dissolve the fluorspar. An excess of fluorspar must be present, and stirring must be vigorous and continued during the dissolving period. At small plants, the fluorspar may be dissolved in a separate small unit which combines the alum and fluorspar. In larger plants equipped with suitable measurement controls, the chemicals could be added to the mixing channel. Calcium fluoride sludge forms and must be removed. A fluorspar treatment unit having 8.0 mgd capacity in operation at the water utility serving Rosiclare and Elizabethtown, Illinois, has been described by Maier. On the basis of that operation, Maier believes that this type of unit can be scaled upwards to treat water flows of large city water systems.

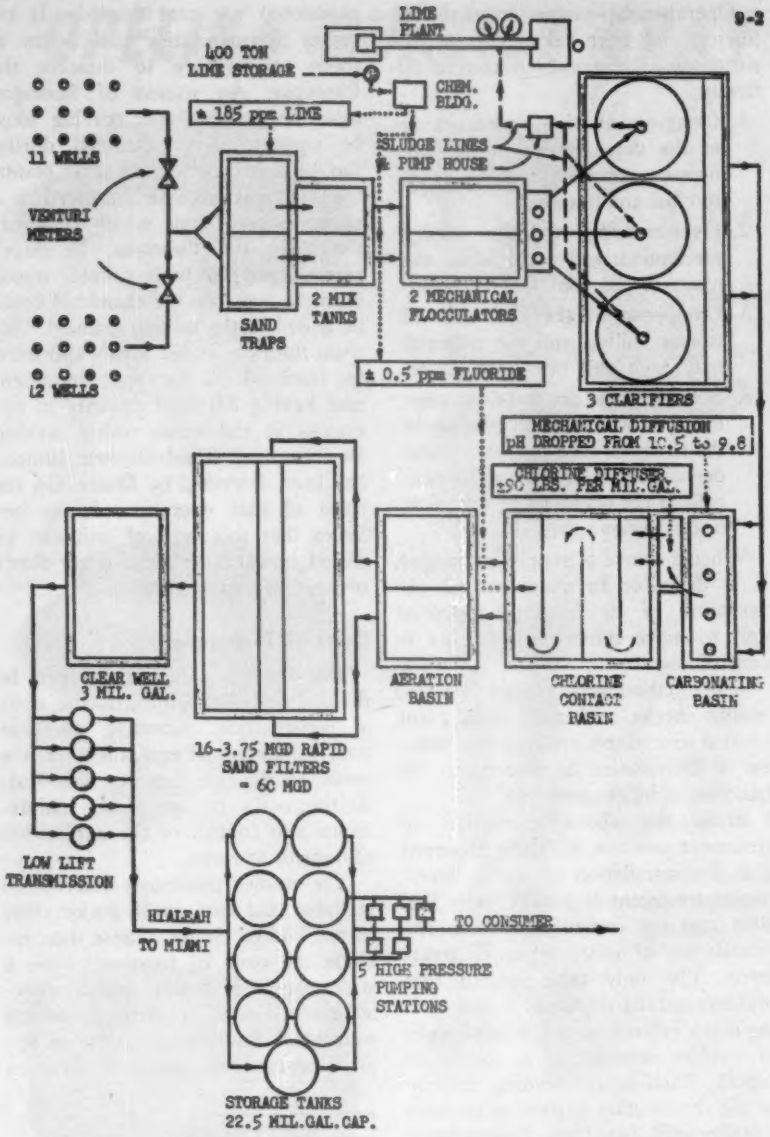
Costs of Fluoridation

The costs of fluoridation can be divided essentially into: 1. the costs of construction, including purchase and installation of equipment; 2. the costs of fluoride bearing chemical; 3. the costs of operation, maintenance and control of the application of fluoride to water.

The studies previously referred to included cost data on 18 major cities in the United States. These data include the costs of treatment over a wide range of water quality characteristics, use of three chemical sources of fluoride, a variety of application methods, and wide variation



WATER TREATMENT diagram, Dalecarlia Filter Plant, Washington, D.C.



FLOW DIAGRAM of Hialeah water treatment plant. Department of Water and Sewers, City of Miami.

of distribution system conditions. Fluoride content of some source waters is little while in others there is nearly enough to satisfy the recommended optimum of 1 mg/l F^-.

The 18 cities provide a flow of 3,147 mgd to a population of 17,801,000. Five of the systems served over 1,000,000 population each and accounted for 34 per cent of the total population being served fluoridated water in 1956.

Construction Costs

Actual construction costs are necessarily related to the time of construction. All of the plants studied have been installed since 1949 when Charlotte, N.C., made its installation. Two, those at Louisville and Indianapolis, began operation in 1951. Eight, including Baltimore, Washington, San Francisco, Pittsburgh, Miami, Providence, Norfolk, and St. Paul, were completed in 1952. Milwaukee in 1953, Denver and Philadelphia in 1954, St. Louis and Toledo in 1955, and Cleveland and Chicago in 1956 followed.

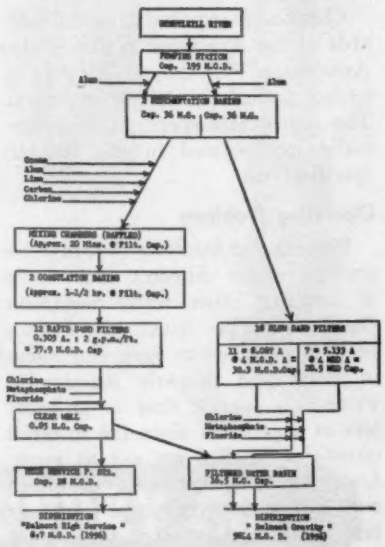
Construction costs are affected by the availability of existing equipment. For example, Indianapolis added no new equipment and Louisville altered its existing equipment. At the Ashburton plant in Baltimore, fluoridation equipment was part of the original construction and was not considered an additional cost. Charlotte was able to use the structure of the existing plant so the construction cost included only the equipment and cost of installation.

Source fluoride content also affects the amount of construction and the sizing of equipment. St. Louis sources average 0.40 mg/l F^- at its Chain of Rocks Plant and 0.49 mg/l at its Howard Bend Plant. On the other hand, source waters at San Francisco, Norfolk and Toledo contain little or no fluorides. More than half of the water used in Denver had a sufficient amount of fluoride from natural sources.

Total costs of construction are, therefore, found to be over a wide range from \$0 to \$382,040. The average cost of construction per million gallons of water to be treated was \$0.763. Construction costs should be amortized in order to estimate an annual charge. Amortization practice is variable. Many cities used either a straight line depreciation over a 10 or 15 year period or calculated the amortization value on a 15 year base at 3 per cent interest. Annual costs of construction ranged from \$0 to \$32,000, the average of 18 cities being \$3,695 or 5.8 cents per million gallons.

Chemical Costs

The cost of chemical is a function of the amount used and unit price. The cheapest of the chemicals is fluorspar. Among the three chemi-



FLOW SHEET for Belmont filter plant, Philadelphia.

Table 1
Water Fluoridation Study
Unit Costs—Water Fluoridation

	4 Cities* Using H_2SiF_6			4 Cities** Using Na_2SiF_6			8 Cities Pop. over 800,000			18 Cities		
	$	¢ cap.	$/MG	$	¢ cap.	$/MG	$	¢ cap.	$/MG	$	¢ cap.	$/MG
Construction Cost												
Total	504,086	5.7	.78	276,709	6.3	1.03	780,795	5.9	.86	876,048	4.9	.76
Annual	40,839	.5	.06	18,093	.4	.07	58,932	.4	.06	66,515	.4	.06
Annual Oper. Cost												
Chemical	577,954	6.5	.90	355,316	8.1	1.32	933,270	7.0	1.02	1,192,892	6.7	1.04
Total	669,824	7.6	1.04	388,084	8.8	1.44	1,057,908	8.0	1.16	1,340,269	7.5	1.17
Annual Cost	710,663	8.0	1.10	406,177	9.2	1.51	1,116,840	8.4	1.22	1,406,784	7.9	1.23

* Chicago, Philadelphia, Baltimore, St. Louis.
** Cleveland, San Francisco, Washington, Milwaukee.

cals used in the 1957 study, sodium silicofluoride was purchased at about $155 per ton, sodium fluoride ran about $280 per ton, and acid was available at $50 to $62 per ton, (24% F^-). The actual amount spent in 1956 for chemical ranged from $15,891 at Providence to $288,000 at Chicago. The average chemical cost amounted to $1.04 per million gallons.

Operations and Maintenance

At treatment plants where other chemicals are used it is difficult if not impossible to determine the specific time an operator spends on fluoride equipment operation as opposed to alum or lime equipment operation. Many treatment plant cost accounts provide only for such items as specific repair as added costs due to fluoridation. When fluoride application plants are situated so that an addition to its staff is needed for operations, laboratory control, and/or other items related solely to fluoride application, a charge is made. In the 1957 study annual operations and maintenance charges ranged from $0 to $81,585. Total operations, including cost of chemical, averaged $1.167 per million gallons treated.

Total Costs of Fluoridation

The average 1956 cost of water fluoridation in 18 major cities was $1.225 per million gallons or 7.9 cents per capita. San Francisco and Providence were median cities with an annual cost of $1.32 and $1.16 respectively. Denver, at $.30 per million gallons, was low and Charlotte, at $2.87 per million gallons, was high.

The investigation included an analysis of four cities using sodium silicofluoride and four cities using acid as a source of F ion. Table 1 provides a comparison of unit costs and shows average construction costs, annual operation costs, and annual cost. The difference in unit costs between systems using acid and systems using sodium silicofluoride is striking. Acid application was $1.10 per million gallons compared with $1.51 per million gallons for sodium silicofluoride. Among the eight cities, the range of costs was $0.71 to $1.85 per million gallons treated.

Another study, made in California[6], contains cost data on nine cities in the San Francisco Bay Area. Exclusive of San Francisco, eight community systems serve fluoridated water to 212,100. The range of initial equipment costs in those eight cities, ranging in population from 2,200 to 80,000, was $0.22-$1.37 per capita. The average initial equipment cost was 56.5 cents per capita. By comparison the 18 city average was 4.9 cents per capita. It is clear that the initial equipment per capita cost is markedly less in larger cities.

Summary

As a summary statement, it may be said that there are no unusual conditions occurring which require peculiar designs for the application of fluorides. The practices which exist in application of chemicals such as alum, lime, activated charcoal, and other chemicals can be adapted to the specific design of fluoride chemical application units. Cost of structures and equipment, selection of equipment and chemical based on ability to perform and cost and availability, provision for accurate dosage control, the normal safeguards for handling dusty chemicals or strong acids, and provision for good laboratory supervision are the essentials to be planned and provided for.

There appear to be economic advantages in lesser costs for construction and feeder equipment in acid plant installations. Depending on a number of variables, a specific installation should not cost more than $2.50 per million gallons annually to construct and operate, and in larger cities the cost should not be over $1.85 per million gallons.

Serviceable and dependable equipment for measuring and feeding fluorides is available from manufacturers. It is a matter of selecting the appropriate units for the needs of a specific installation.

Acknowledgment

This paper has been prepared in part from data obtained by the author in a study of water fluoridation practices in the United States conducted by the Research Division of New York University, College of Engineering, for the New York State Department of Health. The use of this material is gratefully acknowledged.

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2 AWWA Standard for Sodium Silicofluoride—AWWA B702-55. Am. Wtr. Wks. Assn., New York (1955).

3 AWWA Standard for Fluosilicic Acid —AWWA B703-55. Am. Wtr. Wks. Assn., New York (1955).

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5 Maier, F. J., "Advances in the Use of Fluorspar for Fluoridation", *Jour. AWWA, 52,* 1, 97 (Jan. 1960).

6 ....., "Fluoridation Equipment Information for Nine Cities in the Bay Area District". Report, Bureau of Sanitary Engineering, California State Department of Public Health (Mar. 1957).

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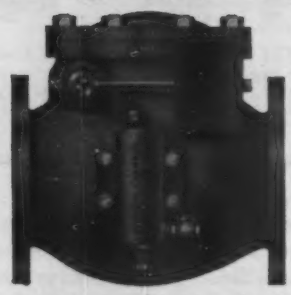
Angle or globe body patterns

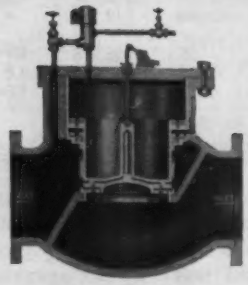
CUSHIONED CHECK VALVES



Swing Check Valve

Cushion chamber on side of body cushions only on last 5% of stroke, prevents any hammer or shock when closing.

Bulletin W-1



Electric Check Valve

Opens only when pump comes up to speed, closes automatically with pump running and shuts down pump when 95% closed.

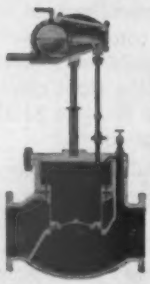
Bulletin W-10

ACCURATE WATER LEVEL CONTROLS

Altitude Control Valve

Maintains water level in elevated tanks within a variation of 3" to 12". May be installed underground.

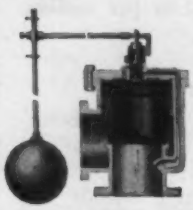
Bulletin W-4A



Cold Water Float Valves

Self-contained float maintains water level in tanks and reservoirs within ½" to 1" variation.

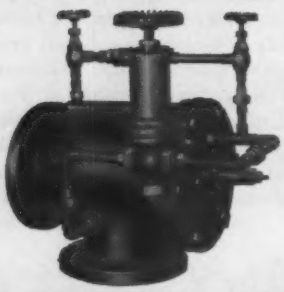
Bulletin W-5



Maintains liquid level control in open tanks, coagulating bins, etc. For high pressure service.

Bulletin W-5

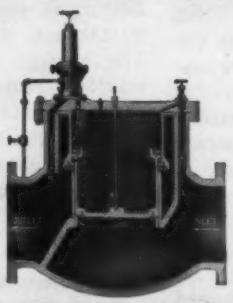
SENSITIVE PRESSURE REGULATORS



Surge Relief Valve

Protects water lines against excessive pressures caused by surges in the system. Fast opening—slow closing.

Bulletin W-2



Water Pressure Reducing Valve

Maintains uniform predetermined delivery pressure regardless of variance in upstream pressure.

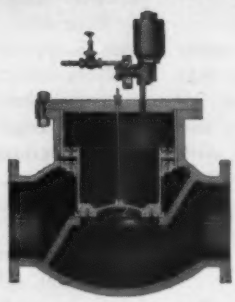
Bulletin W-3A

ONE MAN CONTROL VALVES

Flowtrol Valve

Easily operated by one man regardless of pressure or size of line. Used to replace hard-to-open gate or plug valves.

Bulletin W-8A



Solenoid Valve

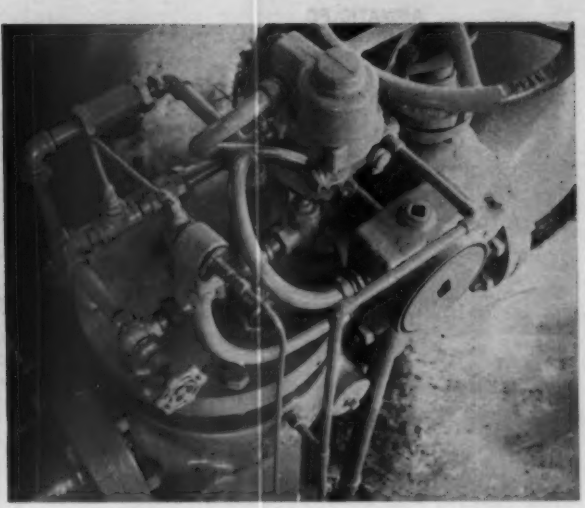
Used where remote control operation or operation by electrical impulse is desired. Adjustable opening and closing speeds.

Bulletin W-7A

GOLDEN-ANDERSON VALVE SPECIALTY COMPANY 1254 Ridge Avenue, Pittsburgh 33, Pa.

Descriptive bulletins—numbered under each valve illustrated above—contain complete technical information. Write for your copies.

W.&S.W.—REFERENCE NUMBER—1961



PUMP and VALVE installation (left) and valve close-up (right) are of . . .

Hydraulic-Powered Valves

by CLARK W. McKEE,
Pittsburgh Controls, Inc., Pgh., Pa.

RESUME: Manhandling large valves open or in closing is a hard slow job. For example, a 24 inch gate valve on a 100 psi line has a total force of 45,200 lbs on its disc. To open or close this valve manually requires some 150 turns on a large hand wheel.

Simple hydraulic pilot systems employing the differential-piston principle can accomplish the same job through fingertip control. The pilot system utilizes the line pressure to perform the work in opening or closing valves.

■A DIFFERENTIAL PISTON incorporated in a valve design can use the line pressure in a water main as power for driving the piston. This is accomplished by using a piston which has half as much exposed area on the small end as that of the large end.

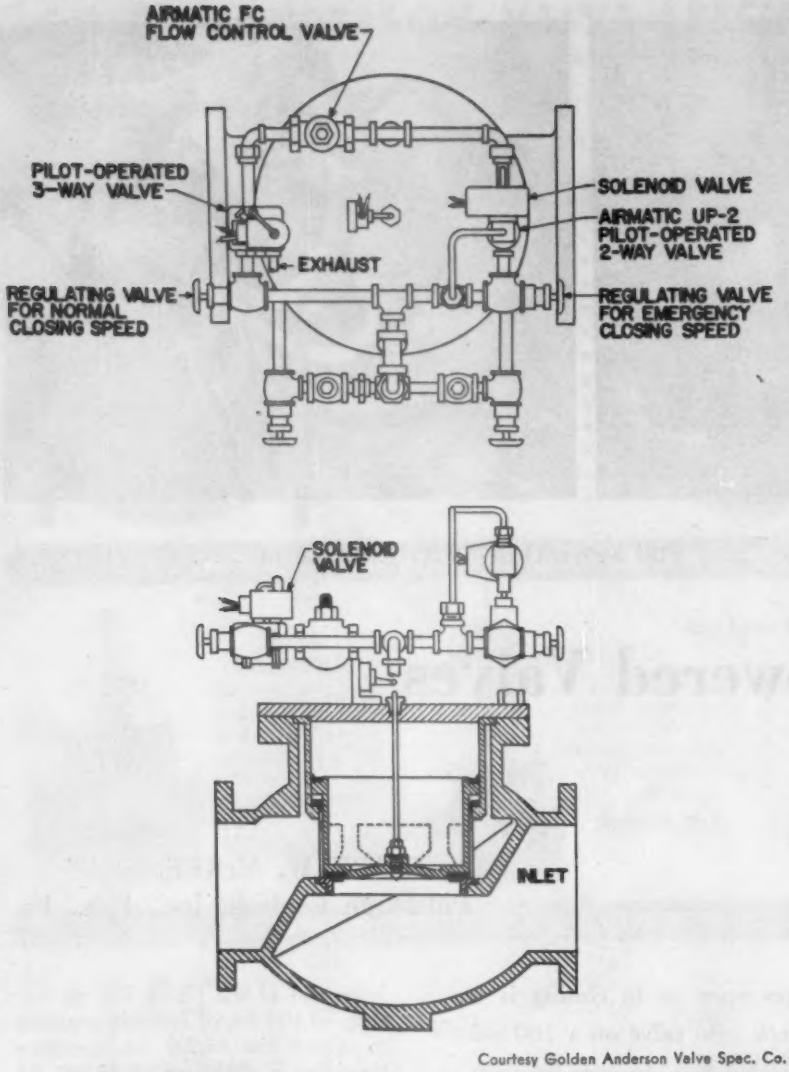
In considering a 24-inch gate valve located on a 100 psi line, the 452 sq. in. disc face would have a pressure of 45,200 lbs against it. To open the valve, it is necessary to overcome this pressure. Manually, two men are normally needed to turn a hand wheel about 150 revolutions to open or close the valve.

By employing a differential-piston whose small end has an exposed area of 452 sq. in., the aforementioned force is available to open the valve. By making the surface area of the large end of the piston 904 sq. in., then 90,400 lbs of force is available to oppose the 45,200 lbs, therefore providing a net force of 45,200 lbs to drive the piston in the other direction and in this case close the valve.

Since the small end of piston actually closes off the flow in the pipe, the controls or pilot system for operating this valve must be centered on the large end of the piston. If the line pressure to the enclosed large end of the piston is closed off and a pilot valve allows the area within the enclosure to be exhausted, the unopposed force on the small end of piston will drive it up and the valve will be open.

To close the valve, the exhaust valve on the pilot system enclosing the large end of the piston is closed and pressure from the main is released forcing the piston down to close the valve.

Large valves ranging in size up to 36 inches can be opened or closed by



Courtesy Golden Anderson Valve Spec. Co.

FIG. 1. PLAN VIEW (top) and vertical section (bottom) illustrate and identify components of valve.

the pilot system which in turn merely controls the presence or absence of pressure on the large end of the differential-piston. These controls can be one-hand manual, push-button solenoid-operated hydraulic or automatic. Automatic operation is provided by solenoid-actuated pilot valves where some electrical occurrence, such as starting or stopping of a pump, energizes the solenoids.

Valve Description

The lead illustrations are of valve installations on the municipal water supply system at Cuyahoga Falls, Ohio and are of the automatic type. These valves were manufactured by the Golden Anderson Valve Specialty Co., Pittsburgh, Pa. The layout of these valves are shown in Figure 1. On top of the main valves is a hydraulic circuit employing two check valves, two pilot-operated valves (actuated by two solenoid valves), and a flow control valve. A header carries line pressure fluid to the top of the piston valve. The line splits; one line leads to a three-way solenoid-operated valve, then through a flow-control valve to a "T" which leads to the top side of the differential piston. This is the control circuit for normal operation of the main valve. The other line splitting off from the header is for emergency operation. It leads through a two-way pilot operated valve and on to the "T" which leads to the top of the differential piston. The solenoid valve mounted directly above the two-way valve (on a fluid line leading from the split header line to the valve) may be electrically connected to a limit switch which in turn may be pressure actuated by a pressure switch or time-relay pilot.

This main line valve and its arrangement of accessory pilot and soleniod valves provides for automatic opening of the valve after pumps are started, and closure of the valve before pumps are stopped.

Ohio Installation

Two such valves are installed on 8-inch water lines which supply an elevated portion of Cuyahoga Falls. Water is pumped through the valves to a 750,000 gal. storage tank. When storage pressure drops to 57 lbs, the pumps kick on and the valves open automatically. After a pressure of 85 lbs has been achieved, the valve closes and then the pumps stop. This kills surge and prevents the loss of high-pressure water from the main system.

The accessory flow control valve is a critical component since it regulates the opening speed of the main valve. This flow control valve, manufactured by Airmatic Valve, Inc., Cleveland, Ohio, employs a large metering stem whose diameter is greater than that of the inlet and outlet parts (Figure 2). This stem differs from the usual needle valve in that it provides considerable more orifice area and thus eliminates much of the usual pressure loss. The large diameter annular orifice allows for extremely fine flow adjustment which can be maintained in spite of pressure changes. When flow occurs in the opposite direction, the poppet lifts off its seat and the fluid passes without impedance through the flow control (regulation for flow in this direction is provided by a needle valve). The usual O-ring and bevel seat design provides for leak-free closing of the poppet.

The emergency control circuit employs a UP-2 two-way universal pilot-operated valve shown in Figure 3. This valve duplicates in miniature the design of the large valve in that it

Installing 14" TY-TON JOINT pipe for a sewer force main.

24" USIFLEX boltless flexible joint pipe being installed for underwater section of water transmission main.

CAST IRON PIPE FOR WATER SERVICE

The practice of using cast iron pipe for water service started in Europe around 1455 and around 1820 in this country. This practice has continued down through the years and it is still the most widely used type of pipe for water distribution systems. The most desirable combination of strength and long life has made and still makes the use of cast iron pipe the most economical in the long run. Our strategically located foundries are well equipped to furnish cast iron pipe and fittings in sizes starting at 2-inch for intakes, pump stations, filtration plants, supply, feeder and distribution mains.

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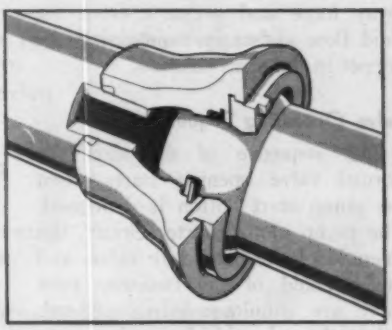
Tyton Joint® pipe is provided with a simple, sturdy, tight push-on type joint for which a self-sealing rubber gasket is the only accessory. It is widely used for water and sewerage service.

Usiflex® boltless flexible joint pipe is of the push-on type with a self-sealing rubber gasket and locked against pull-out by a rugged retainer ring. Ideally suited for submarine and land installations where considerable joint deflection and lock against joint separation are required.



TYPES OF PIPE AVAILABLE

Our cast iron pipe centrifugally cast in metal molds is manufactured in accordance with American Standard Specifications A21.6 (AWWA C106), Federal Specifications WW-P-360a and WW-P-421a. Pit cast pipe is made to conform to American Standard Specifications A21.2 (AWWA C102).

Fittings (bell-and-spigot) can be furnished in accordance with American Standard Specifications A21.10 (AWWA C110) for the short body type 3-inch to 12-inch, also AWWA Specifications C100 for the long body type 3-inch to 60-inch.

Fittings (flanged) are made to conform to American Standard Specifications Class 125 (B16.1) and Class 250 (B16.2) or long-body A.W.W.A. type.

Mechanical joint for cast iron pipe and fittings is made in accordance with American Standard Specifications A21.11 (AWWA C111). Pipe and fittings can be furnished with cement lining in accordance with American Standard Specifications A21.4 (AWWA C104) or manufacturer's standard.

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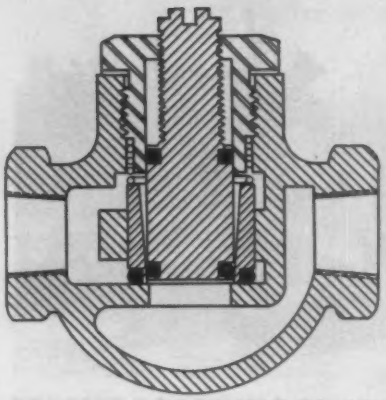


Courtesy Airmatic Valve, Inc.

FIG. 2. FLOW-CONTROL VALVE has unusually large diameter metering stem instead of conventional needle.

also employs the differential-piston principle. Thus, static line pressure applied to the top of the poppet (the piston) assures leak-free sealing indefinitely. When line pressure is removed from the top of the poppet, due to opening of the solenoid mounted above, a spring provides breakaway force and pressure from the fluid flow assists in maintaining the poppet in the open position.

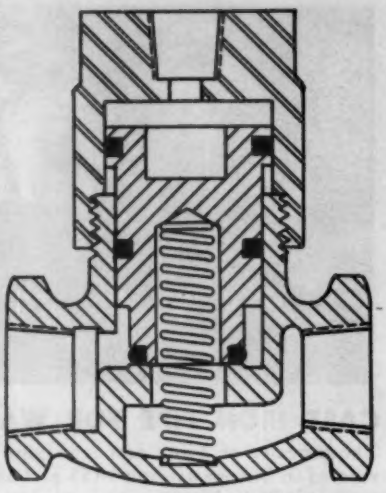
Valve Operating Sequence

The sequence of operation for normal valve opening starts when the pump start button is depressed. The pump motor starter circuit, the solenoid of the three-way valve, and the solenoid of the two-way pilot valve are simultaneously energized. When the solenoid of the three-way pilot valve is energized, it permits exhaust from the top of the differential piston, which begins to move off its seat due to line pressure. The opening speed is regulated by adjustment of the flow-control valve in the pilot line. As pressure underneath the main-valve piston moves it into the open position a position-indicator rod interlocks a limit switch with the pump motor starter circuit.

Normal valve closing is begun by depressing a stop button which de-energizes the solenoid-operated three-way pilot. The pump motor-starter circuit remains in contact because the limit switch contacts are still closed. When the solenoid above the three-way valve is de-energized, the line pressure is admitted to the top of the differential piston, which immediately starts to move into the closed position at a controlled rate of speed as governed by adjustment of a needle flow-regulating valve on the three-way inlet valve line. With fluid moving into the top of the main valve, the poppet in the flow-control opens, so that closing speed is regulated only by the needle valve. When the valve is almost fully closed, the limit switch actuated by the valve-piston indicator-rod breaks contacts in the motor-starter circuit, shutting down the pump motor. The main-valve piston travels the remaining distance to close the valve tight.

Emergency Operation

Emergency valve closing is provided automatically in the event of a power failure. The motor-starter circuit and the solenoids of both pilot valves become de-energized simultaneously which opens both pilot valves to admit fluid to the top of the main valve piston, causing it to move rapidly to its seat. Since both pilot valves are admitting fluid, the

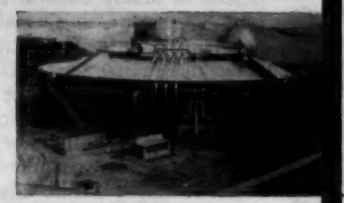


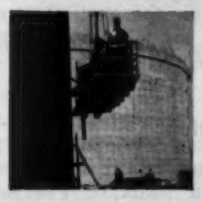
Courtesy Airmatic Valve, Inc.

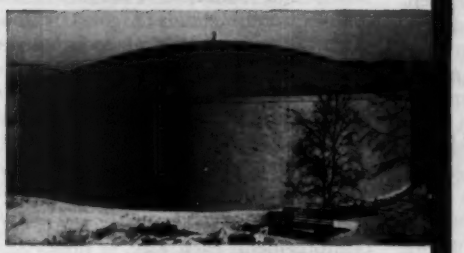
FIG. 3. UNIVERSAL PILOT-OPERATED valve also employs differential-piston principle. Static line pressure applied to top of piston gives leak-proof sealing.

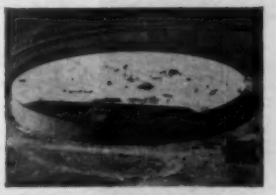
closing speed is always at a faster rate than that of the normal closing speed. Emergency speed adjustment is provided by a needle regulating valve on the two-way valve inlet line. Emergency closing will happen in event of motor under-voltage or overload, or by depressing the emergency stop button.

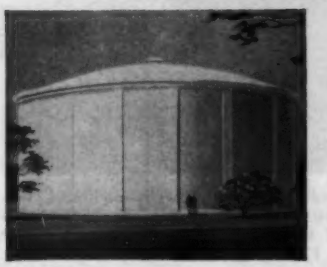
Manual valve opening, after emergency closing, is done by pressing a manual-operator handle which is attached to the three-way pilot valve. The manual operator can be locked in closed position and will hold the main valve open as long as desired. When the manual operator is released, the main-valve piston will immediately start to move again into the closed position at a controlled rate of speed.











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Hayward 2, Calif.
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history of prestressed tanks

The history, development, use and acceptance of prestressed concrete tanks justify their consideration for any storage project.

Preload started designing and constructing prestressed concrete tanks in the mid 1930's. An early example of this work is the 50′ diameter x 100′ high 1.5 MG standpipe constructed for the City of New Britain. Constructed in 1936, it has required no maintenance and is still in constant service. In 1943, Preload introduced its wire winding methods which have been in successful use throughout the world ever since. This mechanical method of prestressing tanks is the only U. S. method of prestressing, including linear methods, which has been exported for extensive use in foreign countries under license agreements. Operations have been or are under way in Algeria, Australia, Canada, Cuba, Colombia, France, Great Britain, Italy, New Zealand, Peru, Union of South Africa, Uruguay and others.

Through 1947, some 470 tanks had been constructed to Preload designs totaling 166,000,000 gallons. This averages 350,000 gallons per tank. Since 1947 and through 1957, over 660 tanks have been constructed to Preload designs; these total one billion gallons and average 1,500,000 gallons per tank. This sharp rise and increase in use in the past decade strongly indicates the widespread acceptance of this method of construction. These tanks have been built for ground and elevated water storage, water treatment, sewage digesters, petroleum storage and many other industrial applications.

In recent years, the use of prestressed concrete for larger and larger tanks has become evident. Last year saw the completion of 2—292′ diameter 13,000,000 gallon tanks for the City of Reading, Pa. Gilbert Associates Inc. were Consulting Engineers. 1958 will see the City of Springfield, Mass. advertise for bids for 2—15,000,000 gallon tanks, 320′ in diameter for addition to their Provin Mountain Reservoir. Bogert & Childs Associates are the overall consultants. The East Bay Municipal Utility District of Oakland, California, is now constructing a 10 MG tank. This Utility has nearly 40 prestressed concrete tanks in service.

In brief, Preload tanks are not something new, prestressing is not a fad, it's a tool to be used by the resourceful designer to help his client solve a storage problem.

what is a prestressed tank

A concrete tank is considered to be prestressed when it is designed and constructed so that when the tank is full, the ring forces created do not cause any circumferential tensile stress in the concrete. Since a prestressed concrete tank is designed as a cylindrical shell with edge restraint, vertical moments result when the tank is initially prestressed and moments of opposite sign but of less magnitude result when the tank is filled. These moments and the resulting tensile stresses and how they are reinforced for are probably the most important aspect of prestressed concrete tank design. A tank wall may be reinforced vertically by prestressed or mild steel reinforcement or a combination of both depending on the magnitude of the residual tensile stress. In any case of residual tension, mild steel reinforcement must be provided.

In a Preload type prestressed concrete tank, the uniformly stressed circumferential prestressing is so designed and placed that no circumferential tensile stresses are created when the tank is full. The Preload tank also provides a well balanced design for the vertical moments due to edge restraint, temperature differentials, backfill, etc., so that total bending tensile stresses are low.

In the above description of a prestressed concrete tank, you will note a strong emphasis on the matter of vertical bending stresses. We accept as axiomatic that no circumferential tension can occur in a wire wound Preload tank; therefore, the major emphasis in design is found in the problem of vertical bending.

Our current practice in designing tanks including full design criteria is described in detail in our Bulletin T-19, "Design of Preload Tanks," which is available on request. These criteria are accepted by agencies of the Federal Government, the Portland Cement Association and many municipalities.

Since 1953, Preload has been using a rubber pad at the base of the wall and under the dome ring of dome roofed tanks in order to reduce the edge restraint as much as possible. This feature has made possible very great improvement in Preload tanks. Dumbbell type rubber water stops are used between the footing and wall and in all floor and wall construction joints so that positive joint tightness is assured. With the rubber pad, on which the wall floats, the restraint is accurately determined from shear resistance data of the rubber furnished by the manufacturer. Vertical bending due to edge restraint is reduced to about 30% of that resulting from even the best of sliding joint preparations abandoned by Preload because of the uncertainty of field results. Owners should note carefully any proposed designs based on sliding base details as nearly 50% of the circumferential prestressing usually must be applied before static friction is overcome and sliding starts. Until sliding does start, the base must be considered as hinged and the vertical stresses analyzed accordingly. The rubber pad base joint contains patented features.

An example of the effect of edge restraint on the vertical stresses is shown in the table on the following page taken from Preload Bulletin T-19.

construction

The construction of the floor, core walls, and roofs of Preload tanks follows sound standard construction practice, and may be of concrete or pneumatically applied mortar depending on the size of the tank.

floors

Floors for Preload tanks may be of either 4″ poured concrete or 2″ pneumatic mortar. In each case ½% of reinforcement, each way, is provided. Pneumatic mortar floors normally do not have expansion joints. Poured concrete floors are usually subdivided for ease of pouring, but each construction expansion joint is sealed with a rubber water stop. For best results, floors should be kept moist or flooded with a thin layer of water until the tank is placed in service.

Preload heavy duty Merry-Go-Round wire winder, stressing .192 wire to 150,000 PSI initial stress. Two 13.0 MG reservoirs—292′ ID x 27′4″ SWD, Reading, Pennsylvania

	RUBBER PAD BASE		SLIDING BASE COEF. OF FRICTION—.5	
TANK EMPTY	OUTSIDE FACE	INSIDE FACE	OUTSIDE FACE	INSIDE FACE
Dead Load	+ 61	+ 61	+ 61	+ 61
Base Restraint	+175	−175	+445	−445
Summation	+236	−114	+506	−384
Temperature	− 70	− 70	− 70	− 70
Summation	+166	−184*	+436	−454*
TANK FULL				
Dead Load	+ 61	+ 61	+ 61	+ 61
Base Restraint	+ 29	− 29	−335	+335
Summation	+ 90	+ 32	−274	+396
Temperature	−169	−169	−169	−169
Summation	− 79	−137	−443	+227

* For the same stresses for both designs provide (454 — 184) = 270 psi with vertical prestressing (32,500 #/ft. of wall).

6 million gallon water tank, Kalamazoo, Michigan

walls

The walls for Preload tanks may be built of either concrete or pneumatic mortar. It is usually economical to use pneumatic mortar when the walls are less than 6 inches thick; concrete when they are thicker. In each case, the forms are designed and erected in accordance with standard construction practice. Cast-in-place concrete walls are usually constructed in segments of full height. Rubber water stops are used in all vertical joints. After the walls have been shot or poured, they are allowed to cure and reach a strength of at least 1.8 times the initial circumferential compressive stress before the circumferential prestressing is applied. Vertical reinforcement as required by the design may be prestressed or standard mild steel bars, or a combination of both. The prestressed reinforcement usually is comprised of high strength bars or wire cables similar to those used for prestressing bridge girders.

roof

Roof design for Preload concrete tanks may be dome, cast-in-place flat slab, precast flat slab or cable suspended; the choice being dependent upon the basic tank design or operating requirements.

The recommendations of the Joint Committees of Standard Specifications ACI-ASCE for Concrete, Reinforced Concrete and Pneumatic Mortar, form the basis of Preload construction specifications, practice and recommendations. Detailed Technical Specifications for the construction of Preload tanks are available on request.

the prestressing operation

A circular tank is prestressed by winding high strength wire around the concrete core wall with a self propelled machine riding on and around the wall of the tank. The wire is stressed by drawing it through a die of smaller diameter than the normal wire. This operation is similar to the wire drawing process used in the mills for making the wire. Accurate stress levels are obtained and the stress around the tank is uniform because there is no slippage of the wire on the tank wall after it is in place in its stressed condition. A stress measuring instrument is available on each job to check the wire stress on the tank.

After the circumferential reinforcement has been placed, a coating of pneumatic mortar is applied to the outside wall to bond the wire to the wall and provide permanent protection against corrosion. For complete protection, the exterior coat of pneumatic mortar need be no more than 5/8" thick. When the design of the tank calls for multiple layers of wire, each under layer is given a 1/8" protective coating. The pneumatic mortar also lends a highly attractive appearance to the finished structure and requires no maintenance.

Preload, its construction licensees or competent local general contractors, experienced in reinforced concrete work, can successfully and economically build Preload tanks. Where local general contractors are to perform the general concrete work, Preload or one of its licensees will serve as a sub-contractor for the specialized portions of the work. We have intentionally "designed out" troublesome construction details and simplified construction requirements. To assist the local consultant, or inspection group of the owner, Preload has an "Inspection Check List" which provides helpful hints. It is also an inspection guide to assist the contractor, by proper inspection, in meeting the intent of the plans and specifications. Preload can furnish a Field Engineer for special inspection duties if desired.

design and cost estimating

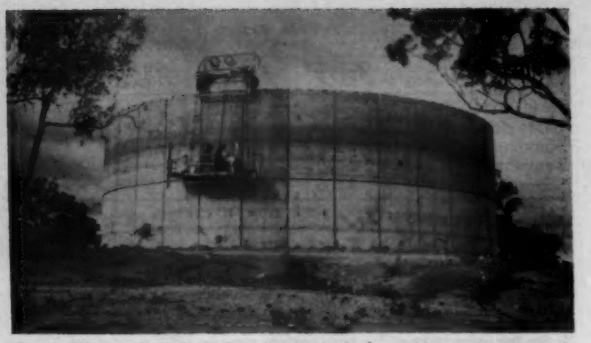
The Consulting Engineer or Owner normally determines the medium of design and construction for a structure. With tanks the choice is between steel, reinforced concrete and prestressed concrete. Advantages and disadvantages can be stated for each. Seldom does an Engineer design a reinforced concrete tank and also a steel tank for taking competitive bids on the same job. It is just as inconsistent to place prestressed concrete in competition with either reinforced concrete or steel. The three types are not comparable in life expectancy, fire resistance, serviceability, maintenance, availability, or initial cost.

The Engineer can easily make a reasonably accurate cost estimate for a reinforced concrete tank. Steel companies gladly give prices for steel tanks to which must be added cost of foundations, painting, and such corrosion control methods as cathodic protection or interior coatings, and evaluated costs of maintaining the steel tank during its life.

Accurate cost estimates for prestressed concrete tanks are easily obtained. On standard tanks Preload or its licensees will furnish estimates accurate within 5% based on current labor and material costs. With the price for the structure accurately determined, the Engineer can make his evaluation and comparison with other

2 MG water tank . . . 160' tower, 195' to overflow, Tyler, Texas

Two 15,000,000 prestressed concrete reservoirs, 320' ID x 28' high. Springfield, Mass.



One 1 MG tank—28' High x 86' ID built from 34 precast concrete panels (or staves) 8' wide each, Canberra, Australia.

methods of design and construction and decide on which to use.

Contract documents may be prepared in several ways:

(1) If a decision is made to use a Preload tank, Preload will be glad to cooperate with the Engineer in preparing engineering plans and specifications to be included with the contract documents for issuance for bids.

(2) In lieu of (1) above, or if alternative methods of construction are decided on, then Preload will cooperate with the Engineer in preparing definitive specifications including detailed design requirements to be incorporated with the contract documents. Bidding contractors should file copies of design calculations and drawings with their bids.

(3) In special cases of alternative bids, and after Preload has had an opportunity to review the proposed alternative methods, it may be suggested to the Engineer that engineering drawings for the prestressed concrete tank should be prepared and issued in the interest of the client. In such case, Preload will assist in the preparation of such plans as in (1) above.

In some cases, the Owner has elected to negotiate with Preload for the furnishing of the prestressing work for the project for a lump sum price that represents a small percentage of the cost of the compiete tank. This price can be included in the contract documents with a stipulation to all bidding general contractors to include this sum as an allowance item in their bid. The general contractor will then engage Preload or one of its licensees as a sub-contractor for the specialized work. This procedure is particularly well suited to situations where only a Preload tank is desired.

Local material prices, labor rates and conditions will influence greatly the final bid price of a prestressed tank just as they do for any other construction. Since a Preload tank is constructed with formwork, concrete and reinforcing steel, over 75% of the contract price is spent in the local community for labor and materials. This should be an important point when steel tanks are being considered as the percentage of local expenditure is just about reversed.

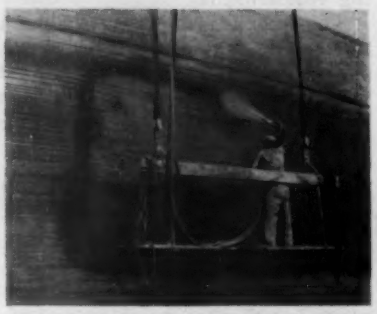
maintenance

Based on average U. S. conditions the larger capacity Preload tanks are generally more economical than conservatively designed reinforced concrete tanks. Smaller tanks may show no economy in initial cost but the advantages of prestressed design frequently justify the selection of a Preload tank. Preload tanks may cost slightly more in bare initial cost than ground storage steel tanks. However, steel elevated or underground tanks generally are more costly than comparable designs in prestressed concrete.

Since alternative methods may be considered, a complete economic evaluation must include the cost of maintaining the facility during the bond period of service life. In comparison with steel tanks, the cost of adequate regular maintenance becomes a substantial item of cost. Depending on local conditions, proper inspection, and maintenance, steel tanks will average 2.5¢ to 4¢ per square foot of maintained surface. This should include floor, interior and exterior surfaces of walls and roof. With column supported roofs the structural system involves a considerable area and should not be disregarded. It must be realized that prices will increase as they have in the past; therefore, the present maintenance dollar will have to be nearly doubled to represent the average cost for a 25 year period.

In summary, the Engineer and Owner should look on prestressing as another medium with which to build their storage tank, whether it be underground, surface or elevated. This is not a new material or concept; it is a recognized and accepted solution.

Wall will float on 5" x 12" x 2" rubber pads. Rubber water stops positively seal all construction and articulated joints.



Pneumatic mortar cover coating for wire protection.

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COAGULANT AIDS*

by J. A. BORCHARDT
Professor of Civil Engineering, University of Michigan

■ Coagulant aids in the broad sense include all those substances which aid or help the process of coagulation. In the water works field, coagulation has been generally understood to mean a reaction between an added chemical and the natural alkalinity of the water to form an insoluble precipitate. The precipitate during its formation and subsequent growth to a macroscopic size acts to enmesh and adsorb impurities in the water. Suspended particles of silt, bacteria, algae, as well as taste, odor, color and general detritus are all included under this heading of impurities. Many of these materials are colloidal in nature and thus the science of the behavior of colloids is an essential part of the science of coagulation and the proper use of coagulant aids.

Coagulant aids function in three ways to assist the process. The first is by speeding up the reaction and thus accomplishing the coagulation in a shorter time. The second is by weighting the precipitated floc and thus assisting in its gravity removal. The third is by mutual precipitation creating a bridge, link, or tie between the colloids or small flocs to make their removal easier. One coagulant aid may act in any of these ways separately or in any combination.

Recycled Sludge

As one example, recirculated or recycled sludge must be recognized as having a beneficial effect on coagulation and thus deserves to be mentioned as a coagulant aid. There is little doubt that softening reactions are considerably speeded up by the use of recycled sludge in an amount varying from two to five percent by weight of the treated water. A committee of the American Water Works Association reporting on the replies from 200 operators of suspended solids contact units revealed that the majority felt "whatever the concept, the effect is to aid coagulation materially"[1].

Herbert Hartung[2] has shown that the results of softening Meramec River water were improved from 15 to 30 ppm by the use of greater than two percent recycled sludge.

The important point here is that the recycled sludge acts as seed for further precipitation of added chemicals, and this is especially true with colder temperatures.

It seems doubtful that any net saving in chemical results, or that a completely stable effluent is ever produced but unquestionably the reactions do proceed more quickly. One authority[3] shows results which indicate that in softening with all other factors constant, the presence of previously precipitated sludge shortens the time of reaction by as much as 800 percent.

Clays

Bentonite or clays must also be classed as coagulant aids. They are often noted as being used to weight a floc or to provide turbidity during critical flocculation periods. Undoubtedly there is some mechanical value due to weighting but probably the exchange properties and charge on the particles are of mere material value in aiding the coagulation. In spite of these factors however, relatively few operators in the aggregate, rely on Bentonite exclusively when cold water and low turbidity produces trouble.

Figure 1 indicates the attractive force exerted between bentonite and colloidal gold. This same cross linking force is utilized when bentonite is added to a coagulation process[7].

Basic Theory

With regard to the mechanism by which coagulant aids function to cause mutual precipitation, reference must be made to the basic knowledge or theory of the process of coagulation. The important factors in coagulation theory have been covered in other papers but should be reviewed here as they apply to the understanding and use of coagulant aids.

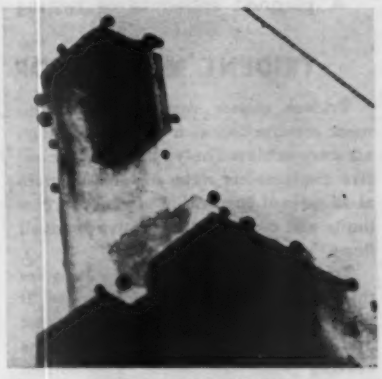

FIG. 1. ATTRACTIVE FORCE exerted between bentonite and colloidal gold.

The impurities removed by the treatment of water are basically colloids having a negative charge. These charges are important because they stabilize the colloidal state and must be neutralized before removal of the impurity is possible.

Neutralization

According to Sawyer[4], the first step in the neutralization procedure is produced by addition of an excess of electrolyte which ionizes to form a cation of opposite charge to that of the colloidal impurity. The cation of the electrolyte tends to

*"This is one of the papers presented at the Short Course on Coagulation of Water for Filtration, conducted at The University of Michigan, Feb. 9-10, 1961. All of the papers presented are included in the course Proceedings, which is available through the Continued Education Service, School of Public Health, The University of Michigan, Ann Arbor."

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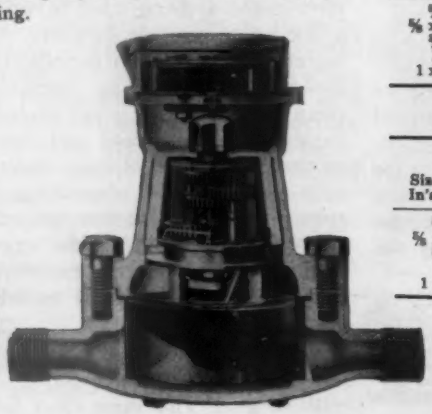
Trident Frost-Proof Meter embodies the original frost-proof meter feature. If the water freezes and expands, the cast iron bottom cap breaks, relieving the working parts from strain. The bottom cap can be replaced at very nominal cost. For warm climates, the Trident Split-Case Meter is recommended.

Among exclusive features for long accurate life are: Gear train is fully oil-enclosed, including the stuffing box, to isolate vital parts from abrasives, turbulence, corrosive elements, and to provide permanent lubrication. Anti-friction thrust roller absorbs disc thrust, making the Trident virtually immune to disc breakage. Heat-proof, hard rubber bushings in gear train and register are interchangeable. Sand ring keeps abrasive material out of working parts. Register has no screws. Chamber is snapjoint. Disc is in three parts, easy to adjust. Guide pins, slots, etc. assist in assembling.



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Size In's	* Wt. Lbs.	Lgth. In's	Wdth. In's	* Ht. In's	Base to Center of Pipe	Del. U.S. Gal. Min.
⅝	10¾	7½	5½	8⅝	1⅝	20
⅝ x ¾	10¾	7½	5½	8⅝	1⅝	20
¾	15	9	6	8⅝	1⅝	30
1	27	10¾	9⅛	9½	2	50
1 x 1¼	27	10¾	9⅛	9½	2	50

Trident Split-Case Meters

Size In's	* Wt. Lbs.	Lgth. In's	Wdth. In's	* Ht. In's	Base to Center of Pipe	Del. U.S. Gal. Min.
⅝	9½	7½	5	7⅝	1	20
⅝ x ¾	9½	7½	5	7⅝	1	20
¾	11½	9	5⅝	8⅛	1⅛	30
1	20	10¾	7½	8⅝	1⅝	50
1 x 1¼	20	10¾	7½	8¾	1⅝	50

*Model 60: add 13/16" to height; add ½ to ¾ lb. to weight.

NEPTUNE METER COMPANY

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Trident Style 3 Meters

Size In's	Wt. Lbs.	Lgth. In's	Wdth. In's	Ht. In's	Base to Center of Pipe	*Del. U.S. Gal. Min.
1½ Scr.	36	12⅝	10	10⅝	2⅝	100
1½ Flge.	40	13	10	10⅝	2⅝	100
2 Scr.	58	15¼	12 3/16	11⅝	3¼	160
2 Flge.	61	17	12 3/16	11⅝	3¼	160
3 Flge.	105	24	16 1/16	17⅞	3⅝	300
4 Flge.	257	29¼	22 1/16	20⅝	4¾	500
6 Flge.	589	36⅝	29	25⅝	5⅞	1000

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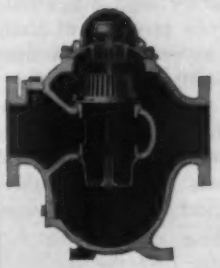
Trident Crest Meters

Size In's	Wt. Lbs.	Lgth. In's	Wdth. In's	Ht. In's	Base to Center of Pipe	*Del. U.S. Gal. Min.
1½ Scr.	65	12⅜	8½	16⅛	6⅝	100
1½ Flge.	65	13	8½	16¼	6⅝	100
2 Scr.	83	15½	8⅞	16⅝	6⅞	160
2 Flge.	85	17	8⅞	16⅝	6⅞	160
3 Flge.	250	24	13⅝	27¼	13¼	350
4 Flge.	260	24	13⅝	27¼	13¼	600
6 Flge.	300	24	14⅝	28⅝	14¾	1400
8 Flge.	500	26¾	17½	30½	15¾	2500
10 Flge.	800	30	26⅝	29½	13⅞	3800
12 Flge.	1200	36	30½	34⅛	16½	5800
16 Flge.	1950	42	36½	40⅞	19¾	11500

Am. Wt. Wks. Asso. & New Eng. Wt. Wks. Asso. Std. Specifications

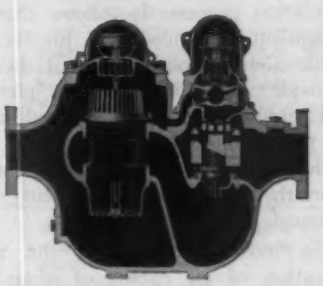


COMPOUND METERS FOR WIDE WORKING RANGES

Use this Compound Meter for services with a maximum demand beyond the range of equivalent disc meters—yet with the probability of occasional small rates of flow. Accurate over a wide working range. Measures high rates of flow through a Trident Crest Meter unit and small flows, which cannot be recorded accurately by the Crest, through a Trident Disc Meter unit. In addition to the standard Trident features of both these meters, a specially constructed valve automatically directs the water to the proper unit, depending on rate of flow. Single cast iron casing. All parts interchangeable.

Trident Compound Meters

Size In's	Wt. Lbs.	Lgth. In's	Wdth. In's	Ht. In's	Base to Center of Pipe	*Del. U.S. Gal. Min.
3	460	33	13⅝	27½	13¼	320
4	475	33	13⅝	27½	13¼	500
6	685	36½	14⅝	28⅝	14¾	1000
8	970	42	17½	29⅞	15⅝	1600
10	1500	45 7/16	20⅝	29⅛	13⅞	2300



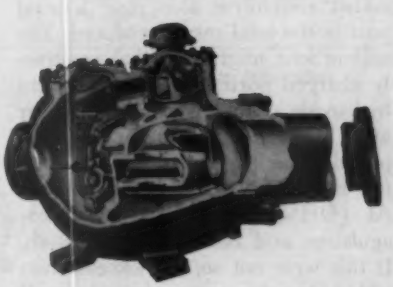
PROTECTUS METERS FOR FIRE SERVICE LINES

Designed for fire line use where both high and low flows occur, and loss of head is an important factor. Meets such requirements with (a) accuracy on all flows and (b) low loss of head plus reliability of operation, satisfying both Water Works officials and Underwriters. Measures low flows through a Trident Disc Meter unit. Large flows are measured proportionally by a Trident Crest unit. Water-way is clear, unobstructed. Both units have standard Trident features which insure accuracy long life and low maintenance cost.

Trident Protectus Meters

Size In's	Wt. Lbs.	Lgth. In's Incl. Incr.	Wdth. In's	Ht. In's	Base to Center of Pipe	*Del. U.S. Gal. Min.
3	700	64⅝	22¾	21½	8	400
4	900	67	24	24⅝	8	700
6	1600	83⅞	29	27½	10	1600
8	2250	89⅝	32¾	30⅞	11⅝	2800
10	3400	98½	38½	37⅝	14⅝	4400

Am. Wt. Wks. Asso. & New Eng. Wt. Wks. Asso. Std. Specifications



NEPTUNE METER COMPANY
Long Island City 1, N. Y.

See Page R-174 for District Offices and Factories

migrate to the surface of the colloidal impurity and result in neutralization of the electrical charge.

The second stage of neutralization then ensues. The excess amount of the coagulant, beyond that used in the cation effect, reacts with the alkalinity to precipitate and form positively charged colloids. These in turn neutralize any remaining colloidal impurity by mutual attraction.

With reference to the initial stage or cation neutralization, the Schulze-Hardy rule is frequently quoted. This states in essence that the trivalent atoms can enter the diffuse double layer more easily than can either the divalent or monovalent ions. The ratio of neutralizing power based on research figures appears to be 700 to 50 to 1 for the tri-di-and mono-valent cations respectively.

Research performed in 1928 at Rutgers University[5] suggested that the hydrolysis products of alum and iron were more important than the cation effect in neutralizing the charges in question. Recent work by Michaels at M. I. T.[6] indicated that thorium, a cation with a valence of four, does not produce the flocculation effect of a polyelectrolyte.

From these examples it is possible to infer that the second stage of neutralization, namely that of mutual precipitation, is the primary or most important phase of the coagulation process. It follows that a coagulant aid need not involve a multivalent cation, but that it should provide a colloid having a plentiful supply of positively charged sites to permit mutual precipitation to be quickly consumated. It is along these lines that coagulant aids are being developed.

In most cases, today, the application of an excess of alum is relied upon as the basic technique for the removal of colloidal impurities. What happens to this excess? In the reaction, the anions of the added electrolyte also play a vital part in the total result produced. The sulfate ions migrate to that positively charged portion of the aluminum hydroxide colloid which is left over after mutual precipitation is completed. The negatively charged sulfate neutralizes the positively charged $Al(OH)_3$, and results in its coagulation and eventual precipitation. If this were not so, any excess alum added to the water would itself merely become an added impurity. Such an eventuality would require close tolerance in the alum additions which would be a great objection from the operators point of view.

The sufate ion in this case is a limiting factor in the process. It might be replaced with a more aggressive anionic agent or coagulant aid.

Silica

The first coagulant aid which attained any degree of prominence as such, was activated silica. This material was interestingly enough, patented by Nahnsen in 1889[7], but owes its present degree of prominence to J. R. Baylis of the Chicago water department.

Briefly, Mr. Baylis found that a tougher, more durable floc was created when silica was present in trace amounts in the water being treated. Apparently, it mattered not whether the silica occurred naturally or was added synthetically. The present product which is widely used is a form of silica dissolved in an excess of alkali. In feeding, the alkali should be neutralized below pH 10.9, and any available form of acid may be used in this neutralization process. Such materials as chlorine, sodium bicarbonate, sulfuric acid, alum and carbonic acid have been used. Obviously, the weaker acids give better control over the process, for as soon as the neutralization is performed, the silica begins to form a gel and will, in short order, become solid unless dilution and mixing takes place. If proper dilution is made, a dispersed colloid is formed. Many operators have made extravagant claims regarding the use of silica. It has also been condemned by many for its apparent shortcomings.

Klinger[8] presents several cases which give rather enthusiastic support to the use of silica in water coagulation. Many of these cases are industrial but the application to municipal practice is quite apparent. The simplicity of his approach belies the constant complaint of operators regarding the difficulty which they have in neutralizing and feeding silica. Klinger used a 55 gallon oil drum and a single mixer as his makeup equipment. He recommends using 5 quarts or 14.6 lbs of 41° Beaume, sodium silicate which should be diluted with 26 gallons of water. In an adjacent container, 3½ lbs of sodium bicarbonate should be added to 6 gal of water. The bicarbonate solution is then added to the silica solution with vigorous stirring. The resulting 33 gal of solution are aged for 1¼ to 1½ hours and then brought to a volume of 50 gal by further dilution with water. The resulting mixture is a one percent sodium silicate solution. The neutralization step is frequently called activation.

Under the electron microscope, particles of the neutralized sodium silicate appear to be spherical. Figure 2 shows such typical particles[7].

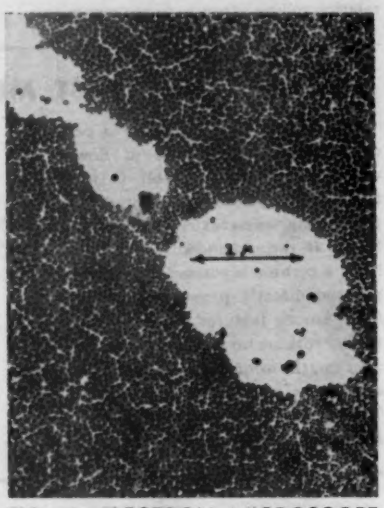


FIG. 2. ELECTRON MICROSCOPE view of neutralized sodium silicate.

Electrophoretic studies indicate that the colloid has an isoelectric point at a pH level of 3 to 4. The colloid is amphoteric in nature and at the neutral pH values normally found in water, the colloidal particles ionize strongly to produce hydrogen ions leaving a colloid having a definite negative charge. (Figure 3[7]). Obviously, since such particles would have the same charge as the normal water impurities, these two would tend to repel each other. On the other hand precipitated alum, in a bicarbonate water would have a higher isoelectric point than the silica, and would tend to be positively charged. The two particles would tend to mutually attract each other.

If this theory is correct, it would appear that in most bicarbonate waters the alum must first neutralize and enmesh the natural colloidal impurities and then the silica should be added to bind the microcrystals of aluminum hydroxide together for

Activated Silica COAGULANT AIDS

PQ's N SODIUM SILICATE

RAW AND WASTE WATER TREATMENT

Activated silica (made from N sodium silicate and a reactant chemical) used with a regular coagulant forms larger, denser, stronger floc and at a faster rate than when the coagulant is used alone. Floc enmeshes more impurities and suspended matter and settles out rapidly to produce clear, sparkling water. Treatment is effective with a wide variety of waters and in all popular flocculating and sedimentation equipment.

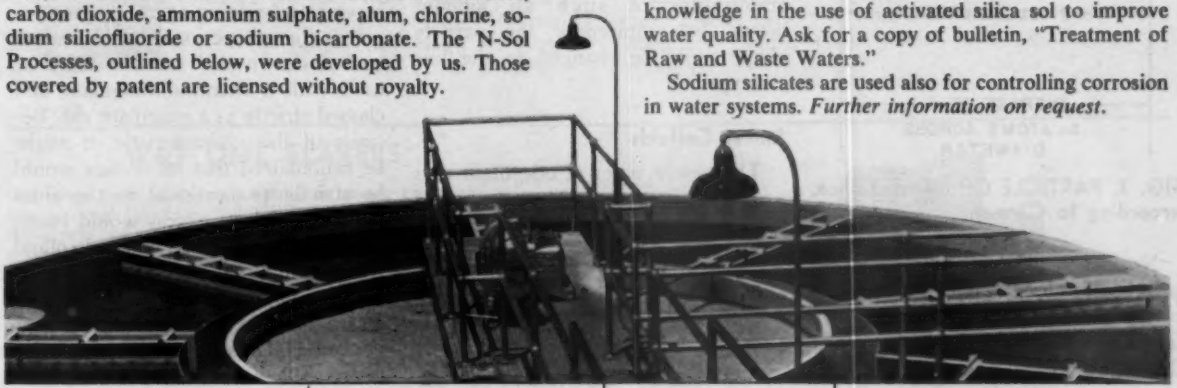
Activated silica sol is a dilute solution of sodium silicate, reacted with acids or acid salts such as sulfuric acid, carbon dioxide, ammonium sulphate, alum, chlorine, sodium silicofluoride or sodium bicarbonate. The N-Sol Processes, outlined below, were developed by us. Those covered by patent are licensed without royalty.

Preparation of the silica sol is done at the plant where it is used. Introduction into the water system can be made either by the "batch method" or by proportioning devices some of which continuously and automatically mix and feed the activated silica sol.

PQ ASSISTANCE

Samples of N sodium silicate (41° Baumé, 8.9% Na_2O, 28.7% SiO_2) and directions for making jar tests are available on request. PQ engineers are glad to share their knowledge in the use of activated silica sol to improve water quality. Ask for a copy of bulletin, "Treatment of Raw and Waste Waters."

Sodium silicates are used also for controlling corrosion in water systems. *Further information on request.*



APPLICATION	PROCESS	REACTANTS	REMARKS
RAW WATER Improves quality Lengthens filter runs Removes high color Reduces turbidity Removes manganese Removes magnesium Removes calcium **WASTE WATER** Recovers reusable solids Prevents stream pollution Clears effluent **IN SUCH INDUSTRIES AS:** Paper Petroleum Metal Finishing Plating Food Textile **ALSO** Radio Active Waters	N-SOL-A (U. S. Pat. 2,444,774)	ammonium sulphate	Easily prepared, either batch or continuous. Chloramines formed in waters previously treated with chlorine.
	N-SOL-B	alum	Reactant readily available, inexpensive.
	N-SOL-C (U. S. Pat. 2,567,285)	chlorine	Reactant usually available where sterilization is normal practice.
	N-SOL-D	sodium bicarbonate	Used where an alkaline salt is desired. For boiler feed water where ammonia is not desired.
	SULFURIC	sulfuric acid	Used where sol of low alkalinity is desired.
	SILICOFLUORIDE*	sodium silicofluoride	Na_2SiF_6 available for fluoridation of water.

*Patent applied for

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PQ SOLUBLE SILICATES
N-SOL PROCESSES
ESTABLISHED 1831

TRADEMARKS REG. U. S. PAT. OFF.

the best removal of the total mass of particulate matter. It is easy to see why particles of alum so bound together would form a tougher floc than alum particles which were merely stuck together by mechanical contact with each other during flocculation.

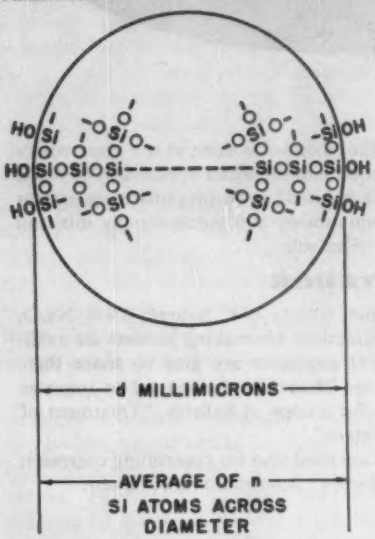

FIG. 3. PARTICLE OF collodial silica, according to Carman.

Normal additions of silica approximate about 25 to 40 percent of the alum fed and probably range from 2 to 10 ppm. Silica may have one or more of the following advantages:

1. It broadens the pH range for good coagulation, and may save on lime or soda ash or on primary coagulant.
2. It helps to form a heavier floc. This floc settles better resulting in longer filter runs.
3. It produces a tougher floc and hence resists shearing in the filters, permitting higher filter rates.
4. Requires less adjustment for temperature variations.

Silica may gum up the feeding equipment and has been accused of plugging up filter beds with excessive carry over.

Colloidal silica probably forms micro crystals having diameters varying in size from 2 to 40 millimicrons. If we assume that the average particle size is 6 millimicrons in diameter and is perfectly spherical, it would have a surface area of 125 square millimicrons. If it could be imagined that this same volume of material were stretched into a cylinder 1 millimicron in diameter, it would have a length of 1000 times its diameter. Its surface area would have been increased to 3,140 square millimicrons or 25 times the initial surface area.

Now if energy factors, chemical ionization or adsorption phenomena are a direct function of the area of interface existing between the colloid and its dispersing medium, then obviously the cylindrical colloid of 1 millimicron diameter (hereafter referred to as a linear-type colloid) must have 25 times the activity of the spherical particle having a 6 millimicron diameter. Thus if 2 to 10 ppm of silica were a normal feed of this coagulant aid, it might be predicted that one-twenty-fifth of such an amount would be required if the particle shape could be changed to the linear type.

Linear Colloids

The newer types of coagulant aids are linear in nature. They consist of chains of many hundreds of carbon atoms linked together in repetitive fashion such that an ionizing site occurs frequently along the chain. This type of molecule has been termed a polyelectrolyte. The nature of the ionizing site renders the colloid positive or negative (cationic or anionic). Non-ionic types of polymers are also available but apparently are less useful. Figure 4 indicates the type of molecular configuration being described here.

In a recent article which describes some of the work going on at the Taft Center, both anionic and cationic coagulant aids in quantities of 0.05 to 0.5 ppm proved to produce exceptionally heavy floc[9]. Such quantities seem to support the theory that the surface area and the charge density of the colloidal particle appear to be the critical parameters in the development of adequate coagulant aids.

One further thought here will shed some light on the tremendous efficiency of floc production at such dilute concentrations. These linear or threadlike colloids have like charges recurring throughout the length of the molecule. Thus one portion of the thread would repel another and the colloid would exist in the water stretched out for its full length. Similarly all adjacent colloids would find themselves in a like situation. Further yet, each of the threads would repel the other resulting in a mass of threads fully extended, yet held apart by electrical charges. In other words, an ideal type of filter. Any colloidal impurity having an opposite charge would be certain to be trapped even though the charge is only mildly evident. Thus it is apparent, that this is a most efficient process and in fact it would be hard to imagine how additional improvements to such a system could be made.

From what has been mentioned about colloids, the anionic coagulant aid would probably serve the same function in alum coagulation as the sulfate ion. It would, in addition serve as a bridging agent in tying together the microcrystals of aluminum hydroxide. In this sense it must be used with a chemical coagulant and classed strictly as a coagulant aid. Because of this characteristic, it might be rationalized that its dosage would be strictly proportional to the alum fed and that any excess would result in some unneutralized residual colloid which would have the same charge as the original water impurities. This excess would probably act as a dispersant and result in a poor quality of treated water. One could conclude that the control of anionic polyelectrolytes must be rather precise. The above observations have been confirmed by recent research results obtained at the Taft Center[9].

The cationic polyelectrolytes on the other hand may be considered as having the ability to act both as a coagulant aid and as a direct coagulant of raw water impurities, since, in general, the charge on the particles involved would be opposite to each other. The binding or cross linking abilities of the polycationic aid would be definitely beneficial to removal, though the built-in ability to self neutralize an excess as does alum is not apparent to this author. If the effect of self neutralization is missing, the addition of such material would also be rather critical as to quantity. Any amount of excess cationic polyelectrolyte would result in particles which would act as impurities themselves. They would not flocculate easily and could be removed only with difficulty. Ap-

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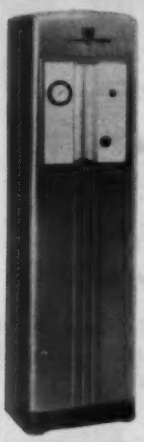

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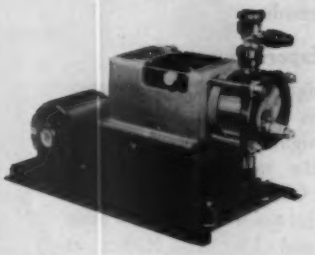

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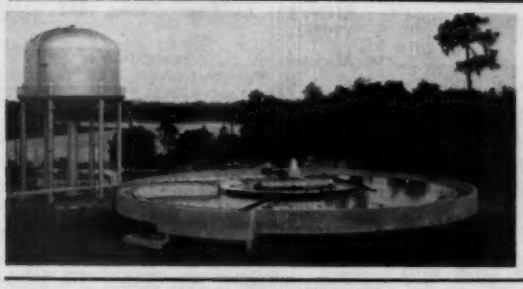
Slakers need no heat exchangers or insulation. Grit is removed automatically without any wastage. Slakers, of various sizes and capacities, all operate with W&T Dry Feeders.

W & T Series A-758 Paste-type Lime Slaker



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parently this was also noted in the research referred to above[9]. Can the coagulant aids be so constructed that they will react with the natural water impurities, or other added components so as to precipitate themselves in excess? Only under such conditions could the materials be really effective as primary water treating chemicals.

Operator's Experiences

When assigned this task, the author wrote to those operators in the state of Michigan who were known to have tried the new coagulant aids. These were: Charles Froman at Midland; Ray Harwood at Flint; Verne Hinebrook and Howard Rafter at Highland Park; George Hazey at Wyandotte; and Eldon Ahles at Flat Rock.

By and large, they agree that dosage at present appears to be critical; also the point of application may be critical. In only one case was there a noticeable saving in total expenditure observed, and this but for a two week trial.

All of these operators expressed optimism that there would be an improvement in use when sufficient experience has been obtained.

At the present time it appears that proper applications of the new coagulant aids are for special situations which don't yield easily to a normal coagulation program. Such situations might be one of the following:

1. When there are interfering or unusual ions in the water.
2. When cold water or low alkalinity or turbidity exists.
3. When there are unexpected shifts in raw water quality requiring abnormal additions of coagulant.

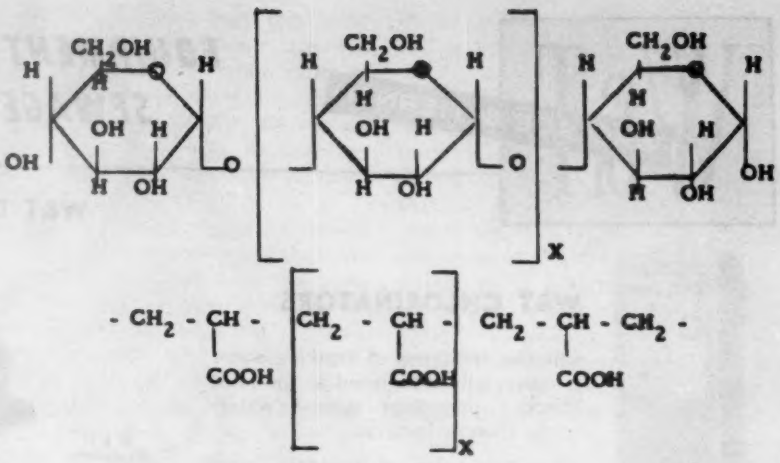

FIG. 4. MOLECULAR CONFIGURATION of a typical linear-type colloid.

4. When specific removal of detergents is required; Taft Center results indicate that the normal 6 percent removal by alum can be increased to 45 percent removal using polycationic type coagulant aids as an adjunct to alum flocculation[9].
5. When algae removal is a problem; Ives work in England based on an electrophoretic study of 10 species of naturally grown algae, indicates that all species studied possess negative charges varying from 716 to 11.6 mv. Removal of these by polycationic aids seems to be a most logical development[9].

In conclusion, the research and development on these new coagulant aids is being carried forward so vigorously that rapid changes are inevitable. All plant operators should keep posted on further applications and development.

The future potential is great and certainly should result in an easier solution to some of your problems and may well prove to actually reduce the cost of treatment.

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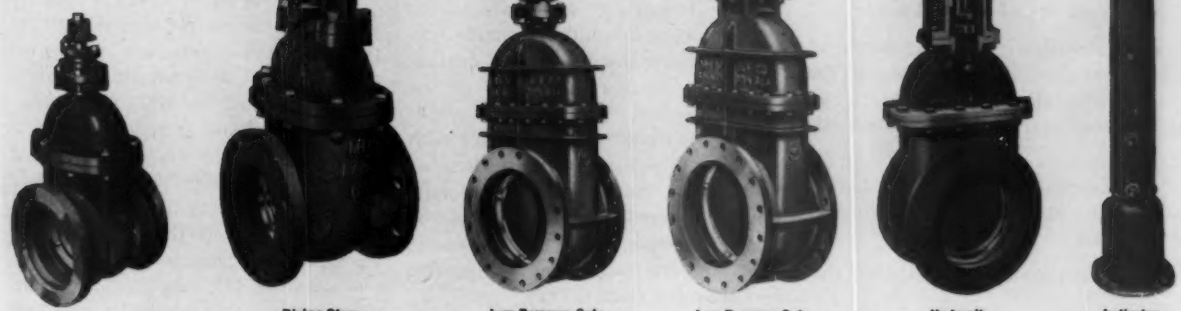

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M & H Compression Type Hydrants conform to latest specifications of the American Water Works Association. They are available either in standard, flush type or traffic models. Hydrants with 5¼″ and 6¼″ valve opening are listed and approved by Underwriters Laboratories of Chicago and Associated Factory Mutuals of Boston and A.W.W.A. Hydrants with 4¼″ and 4½″ valve opening are A.W.W.A. approved only.

Outstanding features include dry top, easy to lubricate, revolving head. Can be lengthened and working parts completely removed without digging up hydrant.

Traffic Model Hydrant | Standard Model Hydrant | Spring Check Valve

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Hydraulically and electrically operated M & H Valves are used in sewage treatment plants, water works, filter plants, etc., to save time and labor since these valves can be operated by remote control for quick, easy closing or opening. They are also used as emergency valves to admit high water pressures into the mains in case of fire. Sizes 2″ to 42″ A.W.W.A.

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M & H Valves and Hydrants are available with Mechanical Joint ends, hub ends, flanged, Ring-Tite, Fluid-Tite, Universal ends and special hubs to connect directly to concrete pipe without using adapters.

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CONTROL OF COAGULATION*

by ELWOOD L. BEAN

Chief, Treatment Section, Water Department, Philadelphia, Penn.

■ The basic tools in control of coagulation are:

1. Chemical and physical tests.
2. Knowledge, or know-how, of techniques for determining the most suitable chemical treatments and physical treatments.
3. Reliable and accurate feed equipment, preferably automatically and/or proportionally paced.
4. Co-operative personnel.

Operation Techniques in Control:

Operation techniques should be developed for the individual plant. There are many different techniques which may be modified to derive those best suited to the individual plant. No attempt will be made to outline many techniques but only to touch on certain phases of the control.

Whatever the water plant organization, laboratory procedure and control should spark the treatment processes. Control should follow this general pattern:

(1) The laboratory division should *determine* the kind and amount of treatment.

(2) It should *specify* these.

(3) The operator should *apply* the specified treatments.

(4) The laboratory should follow through and *check* the results in the various phases of the treatment.

(5) It should *specify changes* when needed.

(6) The operator should make the necessary adjustments.

The frequency with which the control tests should be made depends principally upon the quality, or the variability of quality of the raw water, and the treatment problem. Rather common periods for such "routine" check analyses are three or four hours. Should flash conditions develop, hourly checks should be made on some items. With a source showing very slow changes in quality, less frequent tests may be required.

Data Sheets

Assuming the chemist and operator of a plant are separate individuals, it is advisable that a specification sheet be provided in the operators' headquarters. The chemist then may enter the dosages which he wishes to specify, whenever he desires. If the chemist-operator is a single individual, the specification sheet is still desirable.

Dip samples are inherently poor indicators of the mass of water in a basin. If samples must be "picked up" it is best that the sampling point be equipped so that a flowing sample may be obtained. When possible, it is desirable that sample be piped to the laboratory. When this is done it is essential that the piping material is such that chemical reactions do not vitiate the test results, and that the flow time be as short as practical. It is also essential that air is not introduced into the sample line at the pump or suction, that the sample water is at no point under vacuum, and that the flow be continuous, as stoppage of flow will result in settling of suspended solids which will later be disturbed and produce false results in the sampling.

Flowing samples are not good indicators of floc formation due to turbulence breaking up the floc. Floc formation is best observed in the basins of the plant.

River sources which have many industries on the watershed warrant patrolling, to search out causes of pollution and to prevent pollution. Liaison between the water plant control chemist and managers of the various industries on the watershed is extremely desirable, particularly when the products of the industrial plants are such that spillage or waste could either be hazardous to the safety of the supply, cause taste or odors in the potable output of the water plant, or interfere with coagulation or other processes of the water plant.

The above would include practically all plants producing or using either organics, bitumastics, tars and related materials, poisonous substances, or radioactive materials in substantial amounts. Such liaison and patrolling might not be warranted by the possible effects on coagulation alone but can be justified by the other quality factors involved.

Control of Coagulation

Coagulation has been based on theories of functioning of the ions. However, points causing confusion have been that ions of an alum solution are not always of like charge as ionization changes from positive to negative as pH increases toward 7.0, and ions in a raw water may be of mixed charges. With increasing knowledge and improved control of coagulation there has been increased emphasis on delivering better water to the filters and less reliance on filtration. However, control of the interferences in coagulation, due to mixed and undetermined ionizations has been limited.

Now Zeta potential control has appeared making available a means

*"This is one of the papers presented at the Short Course on Coagulation of Water for Filtration, conducted at The University of Michigan, Feb. 9-10, 1961. All of the papers presented are included in the course Proceedings, which is available through the Continued Education Service, School of Public Health, The University of Michigan, Ann Arbor."

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for measuring coagulating forces, determining the ionization of the particles and, by use of anionic or cationic aids, it is possible to control interferences and the rate and strength of floc formation. Measurements are quickly made by an electrophoretic-microscopic technique. This procedure seems to open wide new fields in control which warrant thorough study and further development.

Tests essential to the control of coagulation are turbidity, color, alkalinity, pH, residual alum, iron, and chlorine residuals. These are used as guides to the consistency of the operation and keys to changes.

As yet, there is no acceptable substitute for the jar test in determining the best chemical treatments. Due to the various factors of hydraulic similitude and the physical factors controlling subsidence, the time of mixing, speed of the mixing, and time of settling in jar tests will be far different than in a full plant. However, with patience and repeated comparison tests the chemist can establish a procedure for the jar tests which will give comparable results.

For this work a multiple mixer is essential. Jars should be set in a water bath, with circulating water at the temperature of water being treated in the plant, and lighting should be provided for good observation of flocculation.

Using chemical dosages identical to those being applied in the plant, a procedure should be arrived at which produces a settled water just like that being applied to the filters of the plant. This procedure must include:

1. Manner of introducing chemicals.
*2. Speed of rapid and slow mixing.
*3. Time of rapid and slow mixing.
4. Time of settling.
5. Manner of transferring sample from jar to test tube for turbidity or color test.

*It may be determined that more than two speeds of mixing are desirable, or that use of only one speed will give results duplicating those in the plant. The latter would generally be true for any plant not equipped with rapid mixers.

Chemical Checks

Once this procedure has been established the chemist is then ready to check any other chemical or combination of chemicals for their value in coagulation. Also from day to day he can readily check the dosages to determine whether those being applied are the most economical for acceptable operation and desired quality.

Equations may be written for the reaction of a coagulant and water to form hydrous oxide floc, but the mechanism of coagulation is not a simple chemical reaction and flocculation. Regardless of provisions made in the plant design, the chemist should determine which chemicals should be applied and the dosages needed. As many as five chemical agents may be needed to produce satisfactory treatment.

1. Coagulant (Al^{+++} or Fe^{+++})
2. Alkali (Lime or Na_2CO_3)
3. Chlorination (Cl_2 or ClO_2)
4. Coagulant aid (Polyelectrolytes, activated silica)
5. Weighting agent (Clay or calcite flour)

All of these and activated carbon should be considered in determining the optimum treatment. Proof that better quality will result, or that savings may result will help to convince officials that moneys should be invested for these purposes.

Floc

Floc formation should be checked in the plant itself every few hours. For ease and accuracy of observation at night it is suggested that lights, about a foot under water, be placed in the slow mix basin, in the settling basin and at point of application to filters.

The floc formation should be observed as to size, development and appearance in the various stages or mixing compartments. Appearance of the water should also be observed. As the successive stages of the mixing are observed the floc development to reasonable size should be obvious, the loose feathery appearance should pass and opalescence of the water should disappear. If very large floc is formed it may be that unnecessary amounts of chemicals are being applied which will be a waste, shorten filter runs and possibly coagulant may pass to the distribution system.

Flocculation should be controlled for the most economical overall operation within limits producing top quality, and required plant output.

Where changes of the speeds of mixing are possible, velocities of mixing should be checked:

1. To determine that degree of agitation is sufficient to produce good flocculation;
2. To determine that peripheral or peak velocities are not too great (exceeding 1.5 ft/sec);
3. To determine whether different speeds might be more effective (with lower raw water turbidity it is known that greater speeds may be desirable to cause more particle contacts.) (Higher mixing speeds may be used in summer due to stronger floc formation.);
4. To determine whether tapering of the mixing would produce better flocculation.

Sludge return should be studied as to the possibility of economy of operation, particularly where raw water turbidity is rather low. The cost of installation of equipment and its operation is generally low. However, if color removal is the problem, sludge return may not be practical as it may be that the floc is easily peptized. Also because the used sludge frequently will not aid in the color removal, probably because color removal utilizes the ionic neutralization and molecular adsorption properties of the coagulant to such a major degree.

Inaccuracies are inherent in grab sampling, spot testing, specification of chemicals and feeder adjustment. Also there is a material lag in dosage change behind water quality. Automatic control of feeder units is desirable where reliable sensing units are available. pH is a factor automatically controlled in many plants. It is so controlled at three points in the Macon, Georgia plant; to 6.5 at rapid mixers; to 7.2 at application to filters; to 8.5 at the storage well. Turbidity has been monitored at a few plants but generally needs better sensing before it can be relied on for automatic control of coagulation chemicals.

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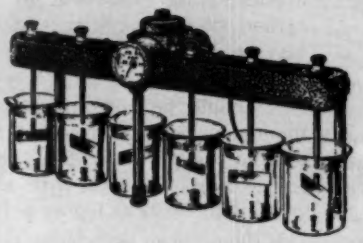

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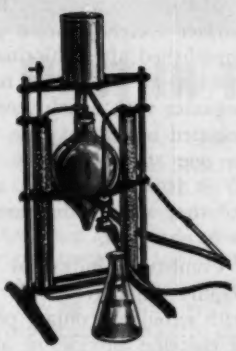

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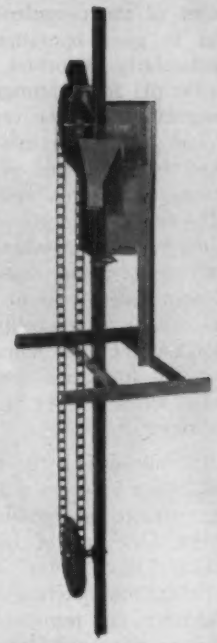

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The standard unit collects a 100 ml sample once every 15 minutes; however, it can be adapted for collecting samples at shorter intervals if required. It can also be equipped for automatic pacing by electrical signals received in proportion to flow from a flow measuring device and transmitter.

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Reasons for Testing

A. pH control near the iso-electric point of the coagulant is essential to good operation. This is particularly important with alum as the pH zone optimum for good coagulation may be very narrow. Width of the zone may be broadened by addition of bi-valent anions such as sulfates, however, pH correction to the optimum is of more practical value than the varying of concentrations. Acid is sometimes used to lower pH and alkali is frequently used to increase the pH. Time required for floc formation increases rapidly when pH is just off the optimum.

B. Alkalinity which is not ample will result in some coagulant being unreacted and passing through filters. One gpg of 17.1 percent Al_2O_3 "filter alum" will react with approximately 7.8 mg/l of alkalinity (in terms of $CaCo_3$). This is the equivalent of 0.256 gpg of 90 percent CaO lime. An excess, or residual, of not less than 15 mg/l of alkalinity is desirable to insure against unreacted alum. (pH is equally important.)

C. Turbidity determinations are essential as they may show:

1. Changes in raw water, indicating that treatment applied should be checked.
2. Changes in settled water, indicating when dosages, or physical factors, are not producing desired clarification, resulting in greater loading of the filters.
3. Opalescence in filter effluent water, indicating improper chemical treatment, improper physical treatment or improper filter operation or functioning.
4. Opalescence in plant effluent water due to preceding, or post-chemical application or the effects thereof. (Turbidity at this point of even 0.2 ppm., by the standard silica scale, cannot be considered as good quality.) If turbidity shows on the plant effluent greater than on filter effluents this may be due to soluble materials in raw water which have passed through filtration but react with the post lime, unreacted coagulant passing filters but reacting with post lime, or impurities in post chemicals, such as iron in the lime.

D. Color determination may indicate the same as noted above; re, the turbidity, except as to the fourth comment. The presence of color in plant effluent greater than in the filter effluents, would indicate the probability that natural organic acids in the raw water had been partially decolorized by lowering of the pH by coagulant applied, and that addition of post-lime to increase the pH had again intensified the color development.

E. Residual alum or iron determinations on filtered waters show, how completely the coagulation reactions have been carried out, how completely these minerals, contained in the raw water, have been oxidized, adsorbed on floc and removed, and the quality of the plant product.

Factors

1. One factor in control of coagulation is the source of supply. A ground water source generally furnishes relatively stable and constant quality of raw water; lakes may be subject to wide variations in quality, particularly with the changing seasons; while rivers are generally subject to frequent changes of much greater magnitude than in lakes.

2. Other factors are; color removal, turbidity removal, color and turbidity removal, combating industrial wastes, combating algae, and removing manganeses or iron. In this age when demands of the public are for absence of tastes and odors from potable water supply, the problem of treatment is not a simple one. Since taste and odor materials may be destroyed by chemical or physical treatments which also are aids in coagulation, their presence becomes a factor for consideration.

If the problem is color removal, the optimum zone of pH for coagulation will generally be critical. The application of chemicals needs to be closely controlled. The floc may be fragile and easily destroyed therefore critical velocities in mixing or in inlets need be watched. The floc may also be light and need weighting to settle in the available time. It may also be that ferric iron coagulant will be more effective or more easily controlled than alum, as the effective pH zone is wider, or that sulphuric acid or an alkali should be used to adjust the pH to the optimum zone. With low pH waters aeration immediately following the application of coagulant, to release carbon dioxide and raise the pH, may be desirable, or pre-chlorination may be needed.

It should be noted that some of the organic compounds in natural waters act as pH indicators, showing lesser colors at lower pH and increasing intensity at higher pH-value.

If the problem is turbidity removal, the nature of the suspended materials may become a controlling factor. If clay is present, the type and ionization are of importance. Some clays are seemingly inert and simply provide good nuclei for the floc to build on, others are active colloids which aid coagulation very markedly, while others, due no doubt to perverse ionic charges, strongly resist coagulation. pH change or electrolytic coagulant aids may produce the required correction, or if high free-chlorine treatment of the raw water is practiced, this may in some cases change the particle ionizations.

Manganese and iron removal from surface waters is most generally accomplished after chlorination to such residual as is required to oxidize the organics with which they may be associated and to oxidize the minerals to one step above the "ous" form. With iron coagulation at pH above 9.3 they will oxidize and precipitate or be absorbed.

Combating industrial wastes may require high free chlorine residual with extended contact period, or use of chlorine dioxide, or activated carbon. Algae may also require these treatments.

3. A third factor in control is the type of facilities provided in the plant. Good facilities in the plant for applying chemicals and for mixing, are vital to good coagulation control. Are feeders accurate and reliable in operation? Are they automatically paced in proportion to flow changes? Are some perhaps controlled to produce certain conditions constantly, such as the correct pH condition?

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Lack of sufficient mixing or flocculation time, or proper agitation have to be offset, in operation, by increased chemical dosages to obtain the effects of mass reaction.

Design of settling facilities must have been based on correct factors of retention time and settling rate. If this is not true, then these deficiencies must be counteracted by use of more chemicals to build heavier, quicker settling floc.

4. A fourth factor in control is; what goals, or parameters, or limiting factors, have been set up, or are to be met? It was not uncommon, years ago, for those in charge of water treatment to set up some goal such as perhaps 10 or 15 above which they would not allow the color to rise. If the color produced dropped below this they would reduce the amount of chemicals applied.

Is there any price on quality? I believe most plants do have to watch their budget to some extent and parameters do have to be set up as a practical matter. The cost of removing the last traces of some material may be prohibitive. Parameters should always be set high enough so that nearly all customers will be pleased. If means are found to improve results, then these parameters should be revised toward an even higher quality.

5. A fifth factor in control is the plant size. In a large plant one or more chemists may be assigned to each shift around the clock, or assigned only to the day shift. The extent of pollution of raw water and rapidity of change in pollutional loadings, also the degree of treatment given, will generally determine which of these should be adopted for control. In a small plant the filter operator may be required to double as pseudo-chemist and determine the dosages which he also must apply.

6. The sixth factor in control is quality and training of personnel. Each year, throughout the country as a whole, the production of potable water is becoming more and more a case of chemical manufacture. Trained chemical personnel is needed to supervise treatment in plants both large and small.

The operator of years ago who cut back the chemical dose because color was below 10 or 15 did not know of the side reactions which resulted. Similar results may occur with any parameter if the chemist is not well trained and alert. Best results from a plant are always dependent on intelligent, alert operators. Training schools are invaluable for all.

Application of Chemicals

Points of application of chemicals, with relation to the physical steps in the treatment processes, should not be arbitrarily chosen. Plant designers may have provided for certain locations only, however the chemist should study the possibility of improving the treatment by changes of location. For instance, it is not uncommon for lime, alum and chlorine all to be applied at practically the same point. In some waters this order of application would produce good results. In probably far more waters the reverse order of application would produce far superior results, particularly if time for thorough diffusion of each was available.

Alkalinity and pH are used to check the feeding of chemicals. They indicate variations in actual dosages. They are particularly important since excess alkalinity is necessary to insure full coagulant reaction and to maintain the pH. Should pH wander outside the optimum zone, time for coagulation would increase, preventing good results. Full automatic feeding control on acid or alkali, for pH control, is therefore desirable. This is particularly true in view of the time factor of lag between water change and application change with grab sampling, analysis, specification, and feeder adjustment, resulting in underfeeding or overfeeding.

Application of chemicals should be uniform in proportion to flow rates. Feeders should be automatically paced directly from the flow measuring device. This can be done for any commercial feeder by use of available control units: for dry feed producing; proportionally variable speed of feeder drive, time-cycle control of feeder drive, or variable vibration or oscillation of feeder; for liquid feeds using rotameter or orifice types—the time cycle control of solenoid valves, or tank types—the control of rate of dropping of the orifice. Most such equipment must be calibrated for delivery at various settings. Graphs or chartings will be prepared which will indicate in effect the grains per gallon which will be fed at various settings. Once this is done the operator need only adjust the setting to correspond to the gpg specified by the chemist.

Feeder types are too numerous to describe here but those types in common use will be mentioned, they are:

Dry Feeders

- Batch type gravimetric (loss-in-weight)
- Belt type—gravimetric
- Rotolock (spool) type
- Volumetric rotating plate
- Oscillating hopper type
- Oscillating plate type
- Oscillating throat type
- Vibrating type
- Rotating screw or worm type

Solution Feeders

- Rotodip type
- Electro-chemical types (controlled dropping of feed outlet)
- Gravity orifice types
- Rotameter types
- Diaphragm type; or other pumps
- Various pot types(—in older plants)

Use of Records and Data

Records of all laboratory determinations and researching should be carefully made and preserved. Likewise reliable records of actual applications should be preserved for review and future reference and study. Results in the plant can only be studied with reference to the dosages actually applied, therefore the effectiveness of treatment must be studied with relation to these operators' records.

Provided the raw water source is free of major variability in industrial waste pollution the coagulant range most likely to produce optimum flocculation may be quickly approximated from past records of demands with relation to turbidity or color. Charts should be prepared from past data and revised to the more recent past data at intervals. These should be looked on only as approximations and dosages should be checked by jar tests since the turbidity or color may be due to unusual materials with a different ionization, particularly if the source is a river.

Laboratory test data should be used each day by the chemist to determine whether better quality may

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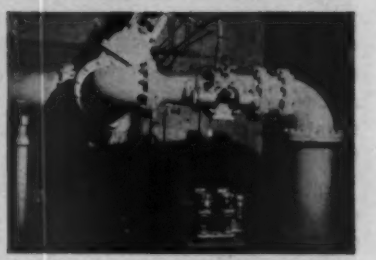

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Bulletin 1220.

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result or a saving be produced by change in coagulant dosage, particularly those most expensive treatments. Experience will quickly establish the factors which apply to transferal of the laboratory data to plant operations.

River water source data is particularly valuable to establish variations which are normal, and for day to day review as to the appearance of abnormal conditions or materials. Abnormal materials may be the signal for a survey of upriver conditions.

Operating and chemical data indicate the consistency or inconsistency of control which is attained. Review of these data will indicate what parameters of operation and of quality may be set up for future guidance, and at what cost these may be met. For instance,

1. What turbidity of water applied to filters is most desirable considering effluent quality, filter operation and washing, and costs?
2. What chlorine residuals after pre-treatment are necessary to produce desired treatment effects and carry residuals to the post-chlorination point?
3. What pH and alkalinity are necessary in plant effluent to control corrosion and consumer complaints?
4. What is the maximum alkalinization which can be carried at pre-treatment to reduce the post-treatment load?
5. What color and turbidity standards should be set up, to be continuously maintained in plant effluent?
6. What chlorine residual content should be set up, for maintenance in the plant effluent, to produce desired residuals in distribution?

These are illustrative of the many parameters needed for control of a modern treatment plant.

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SODA ASH	Bulk cars 100-lb. bags	Neutralizing and adjusting pH level
CAUSTIC SODA	50% and 73% Liquid in tank cars Solid in 100-lb. and 70-lb. drums Flake in 100-lb. and 400-lb. drums	Neutralizing and adjusting pH level; water softener maintenance
PITTCHLOR® (Granular high test calcium hypochlorite) 70% available chlorine	4 3¼-lb. cans per carton 9 5-lb. cans per case 100-lb. drums	Intermittent chlorination; standby supply
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THEORY OF COAGULATION*

BY DR. A. P. BLACK

President, Black, Crow & Eidsness, Engineers; and Research Professor of Chemistry and Sanitary Science, University of Florida, Gainesville, Fla.

■ Coagulation is probably second only to chlorination as a method for the treatment of public water supplies. Since it is carried out for the removal of suspended and colloidal impurities, it is practiced in the case of most impounded surface supplies.

Many of the major cities of this country, including Chicago, Detroit, Philadelphia, Washington, St. Louis, Sacramento, Birmingham, and Atlanta employ coagulation practices as well as hundreds of smaller towns and cities. The volume of public water supply treated by coagulation totals several billion gallons per day and many millions of people consume coagulated water. Moneywise, the cost of coagulating public water supplies in this country alone amounts to thousands of dollars daily.

In spite of these impressive figures, our knowledge of what takes place during the complicated process of coagulation is far from complete. It seems certain that the use of aluminum and iron salts as coagulants was begun because their hydrated oxides closely resemble the "schumutzdecke" or slimy layer which forms on the surface of slow-sand filters and in part enables them to perform as efficiently as they do. However, many investigations conducted since coagulation was first practiced have shown that the explanation of the true action of the salts of aluminum and iron as coagulants is not simple. We are forced to resort to an understanding of the properties and behavior of colloidals to understand at least in part the mechanism of coagulation.

*"This is one of the papers presented at the Short Course on Coagulation of Water for Filtration, conducted at The University of Michigan, Feb. 9-10, 1961. All of the papers presented are included in the course Proceedings, which is available through the Continued Education Service, School of Public Health, The University of Michigan, Ann Arbor."

Development of Coagulation Theory

The development of theories with respect to the basic mechanisms of coagulation during the past few years is important. I shall refer to a few important papers, to evolve the theory. Much important work has been omitted and, since 1923 has been arbitarily chosen as the starting point, much good work done previous to that time is likewise not referred to.

1920's

In the period 1923-25 Theriault, Clark and Miller[1-6] published a series of papers and laid the foundation for modern coagulation theory. These workers concluded that:

1. There must be present a certain minimum quantity of aluminum of ferric cation;
2. There should be present an anion of strong coagulating power; and
3. The pH must be carefully adjusted.

In 1928 Bartow and Peterson[7] continued this work by investigating the effect of many ions on the pH zone of rapid coagulation.

In 1928 Professor Sante Mattson[8] of Rutgers University published his electrophoretic study of coagulation of clay colloids and indicated the applicability of his conclusions to water treatment. His work minimized the importance of the Schulze-Hardy rule in that he demonstrated that the products of hydrolysis of aluminum and ferric salts are more effective than the trivalent cations in reducing or neutralizing the zeta potential of colloidal particles. He found that alum exhibits its greatest effect on the zeta potential of clay particles at pH 5.2, which is well within the pH zone of hydrolysis of aluminum salts delineated by Miller.

1930's

In 1933, Black and Bartow[9-11] again demonstrated the effect of other ions on the pH zone of rapid coagulation using both refined jar test techniques and a pilot plant. Further, using both ferric sulfate and ferric chloride, they demonstrated that there exists a zone falling usually between pH 7.5 to 8.5 within which flocs form slowly or not at all and ascribed the existence of this zone to the reversal of the "charge" on the floc particles.

Clark and Price[12] carried out electrophoretic studies on the sludges produced in lime-soda softening and found both $CaCO_3$ and $Mg(OH)_2$ to be positively charged throughout the entire pH range of water softening.

In 1937 Baylis[13], and Graf and Schworm[14] announced the discovery of activated silica and demonstrated its often spectacular effects upon floc formation.

1940's

In 1940 Larson and Buswell[15] repeated the work of Clark and Price and confirmed their finding that magnesium hydroxide is positive throughout the entire pH range. However, they found $CaCO_3$ to be negatively charged and alum flocs to be always positive below pH 7.6 and always negative above pH 8.2, the isoelectric point, therefore, falling somewhere between the two values.

In 1948 Black[16] attempted to summarize existing theory as to the mechanism of coagulation.

As we shall see, later work has made it necessary to substantially revise these concepts of the mechanism of water coagulation.

In 1948-49 Eliassen and Eckenfelder[17] carried out a series of stud-

ies of coagulation employing both aluminum and ferric salts.

It seems worthwhile to call attention to the fact that most of the laboratory research referred to was carried out using pure salts, synthetic waters, and in the presence of different concentrations of electrolytes commonly found in natural waters. The relatively narrow zones of rapid floc formation identified under these conditions were assumed to apply in the presence of clay turbidity or organic color, an assumption which later work was to prove erroneous.

In 1949 Langelier and Ludwig[18] were among the first to emphasize the chemistry of clay suspensions. They proposed the theory that the aluminum ions added first replace all of the exchangeable cations present in the colloidal system.

1950's

The year 1952 witnessed the advent of the synthetic polyelectrolyte coagulant aids which, in turn, revived interest in the older natural polymers. Ruehrwein and Ward[19] compared the effects of polycations and polyanions on clay suspensions.

Flocculation experiments showed that polycations were effective coagulants alone, while polyanions served as coagulant aids after a flocculating dose of a metal coagulant had been added. To explain their results, Ruehrwein and Ward[19] postulated the formation of polymer bridges between particles.

Michaels[20] suggested that a polymer must become adsorbed on the solid surfaces of the particles if it is to contribute to flocculation. Two different actions may then follow: (a) If the polymer bears a sign of charge opposite to that of the particle surface, it may reduce the electrokinetic potential enough to permit particle aggregation. (b) The polyelectrolyte may adsorb on more than one particle binding them together. This operation may be performed by both cationic and anionic polymers. The aggregating action of anionic or nonionic polyelectrolytes is caused by adsorption (via ester formation or hydrogen bonding) of hydroxyl or amide groups on the solid surfaces with each polymer chain forming bridges between more than one particle. Controlled hydrolysis experiments show that anionic polyelectrolytes should have enough charged sites to extend the chains to permit inter-particle bridging without increasing the charge density enough to interfere with adsorption on the negative particles. This also explains why partial zeta potential neutralization by a metal coagulant increases anionic polyelectrolyte adsorption by reducing the repulsive force between the negative polymer and the negative particles.

Kalchalsky[22] and Conway[21] published discussions of the behavior of polyelectrolytes and LaMer and Smellie[23] published a series of four papers dealing with the effectiveness of a large number of natural and synthetic polymers and poleylectrolytes as coagulant aids in the flocculation, subsidence, and filtration of phosphate slimes.

In 1958 Cohen, *et al.*[24] ran coagulation tests on synthetic and natural waters using anionic, cationic and nonionic coagulant aids. The anionic aid was found to be effective only as an aid to the metal coagulants. Its effectiveness was nearly independent of pH, alkalinity, hardness, and turbidity. However, the optimum dosage of anionic aid increased linearly with the alum dosage. The pH range of alum flocculation was not extended by the anionic aids.

The cationic compound was both a coagulant alone and a coagulant aid. It was effective only in moderately mineralized water and allowed alum coagulation in the presence of such interferences as sodium tripolyphosphate and lignins. Algae, which are negatively charged, are also removed from water by cationic aids. The nonionic aid was less effective than either the anionic or cationic aids.

In 1956 Babcock and Knowlton[28] suggested that chemical coagulation could be automatically controlled by determining differences in total conductivity of the water before and after the addition of the coagulant and presented data based on actual plant operation in Beverly, Mass. Consequently, this possibility was carefully studied by Granstrom and Shearer[29] who concluded that the location in the break of the conductivity curve is determined by the alkalinity present in the water and bears little or no relationship to the optimum alum dosage for colloid removal. They point out, however, that this does not necessarily mean that with certain waters—probably those having low dissolved solids—the differential conductivity method might not be applicable.

In 1959 Woxholt[30] presented data substantiating the claim of Babcock and Knowlton[28] that conductivity is of value. He pointed out that more than 50 percent of the suspended solids in highly mineralized Mississippi River water settle out in two hours or less, whereas less than 1 percent settle out in the slightly mineralized Vaal River water after 24 hours.

In 1958-60 the University of Florida group[25-27] published part of a series of papers presenting electrophoretic studies of water coagulation with and without the use of natural and synthetic polyelectrolyte coagulant aids.

This review would not be complete without mentioning Packham[31-33] and his associates of the British Water Research Association. In the first of three publications he reviews the basic theory of coagulation and in the other two he presents data on the coagulation of suspended solids from nine English rivers. The work is extremely well done but because regulations of the Association prohibit quotations or summaries without expressed permission, the original publications should be consulted.

Properties of Colloids

Colloid chemistry was originally defined as the physical-chemical phenomena of particles within a certain range of particle size, perhaps 5-200 millimicrons. This definition, however, was soon found to be inadequate for the most important properties of colloids are surface effects at interfaces and the surface areas involved are very large. It is important, therefore, that we understand the nature and extent of the forces that surround the tiny particles of such sols and give them their remarkable properties.

Instability and Stability Factors

The two most important instability factors are the Brownian movement and the London-Van der Waals forces of attraction. The Brownian movement is the movement imparted to the suspended sol particles because

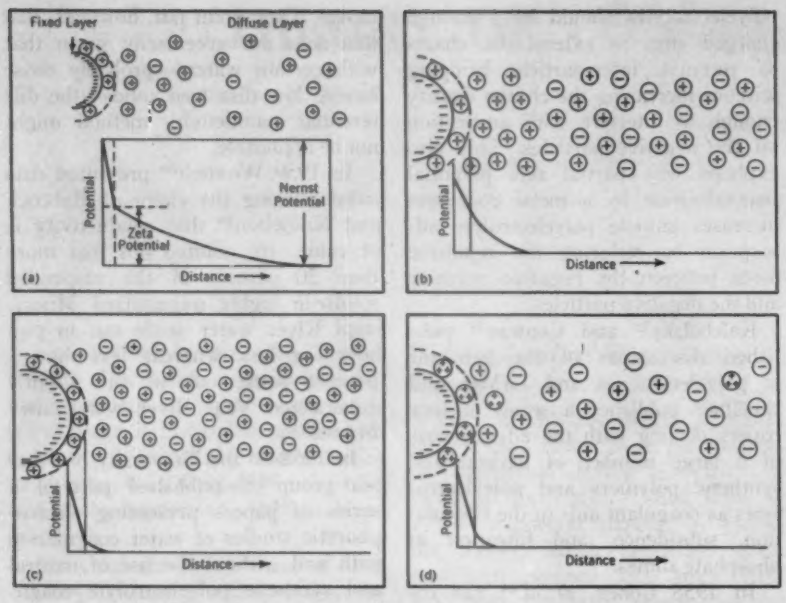

FIG. 1. SOURCE OF ZETA Potential and Effect of Ions of Opposite Charge. (a) A negative colloidal particle in a low concentration of monovalent ions. As the ion concentration increases from (b) to (c), more positive ions enter the fixed double layer and the zeta potential is reduced. In (d), a trivalent positive ion has entered the fixed double layer and so reduced the zeta potential that coagulation would probably result.

of their impact with invisible, rapidly moving particles of the medium. It is, therefore, essentially a thermal effect that tends to drive particles closer to each other and even causes them to penetrate the force fields surrounding each particle. The London-Van der Waals forces may be described as molecular cohesive forces that increase in intensity as the particles approach each other. They become more effective with decreasing particle size.

The most important stabilizing factors are hydration and the zeta potential. Hydration is the property possessed by some particles to attract relatively large numbers of solvent molecules to their surface. When the solvent is water, such particles are called hydrophilic, and contact between particles is hindered by the solvent "sandwich".

Nature of Zeta Potential

Zeta potential refers to a surface charge of colloidal particles which causes the particles to migrate in an electrical field to the pole of opposite charge. Zeta potential may be the result of selective adsorption of ions from the solution or of residual valance forces, or both. The original Helmholtz picture of a charged colloidal particle showed a closely held double layer of charges of opposite sign. Electrophoresis—the movement of charged particles in an electrical field—could not, however, be explained by such a picture. Gouy and Stern proposed the diffuse double-layer theory, which pictures a stationary layer of ions on the surface of the particle surrounded by a movable diffuse layer extending out into the solution. A rapid drop in potential occurs between the particles and the stationary layer, and a much more gradual potential drop occurs between the stationary layer and a point in the solution at which electroneutrality exists. The overall potential is called the chemical or Nernst potential, whereas the lesser potential between the stationary layer and the solution is called the zeta potential. The latter makes it possible for the particle to move within a charged electrical field. Because the motion of charged particles in an electrical field is independent of their size or shape and dependent mainly on the zeta potential, the measurement of particle mobilities affords a rapid and accurate method of determining the magnitude of zeta potentials. Because all the particles of a given sol possesses the same zeta potential, it acts as a repulsive force preventing the individual particles from approaching each other. (Figure 1).

Coagulation of Colloids

Colloid chemists long ago showed that coagulation results when ions with a charge opposite to the charge of the colloidal sol are added to the colloidal solution. The ionic atmosphere of the diffuse layer surrounding each particle expands and contracts as the salt content of the solution is decreased and increased. As the concentration of the added ion is increased, the diffuse layer is contracted until a point is reached when the London-Van der Waals attractive forces are stronger than the repulsive forces of the zeta potential, and coagulation results. The valence of the ion of opposite charge is all-important, and the observed effects, in general, follow the Schulze-Hardy rule, which states that a bivalent ion is 50 to 60 times more effective than a monovalent ion, and a trivalent ion 700 to 1,000 times more effective than a monovalent ion. A colloid may also be precipitated by the addition of a colloid of opposite sign. This is called mutual coagulation.

Water coagulation can be interpreted in terms of these colloidal phenomena. The two coagulants most widely used are aluminum and ferric sulfate. Both supply trivalent cations. Both turbidity and organic color in water are present as negative colloids, so the significance and importance of the trivalent positive charge becomes immediately apparent. Also, when either aluminum or ferric sulfate is added to a water in the pH range of optimum coagulation, hydrolysis takes place. The formation of insoluble colloidal basic salts probably precedes the formation of colloidal aluminum oxide sols. Both possess positive zeta potentials and have the ability to precipitate negatively charged color or turbidity by mutual coagulation.

Colloid chemists have long recognized that rapid coagulation of a colloid sol usually takes place shortly before the zeta potential has been completely neutralized. Electrophoretic studies show that this is generally true where either alum or ferric sulfate is being used for the coagulation of either organic color or turbidity.

When turbidity is present as clay, a further factor must be considered. The metallic ions in the diffuse double layer surrounding a clay part-

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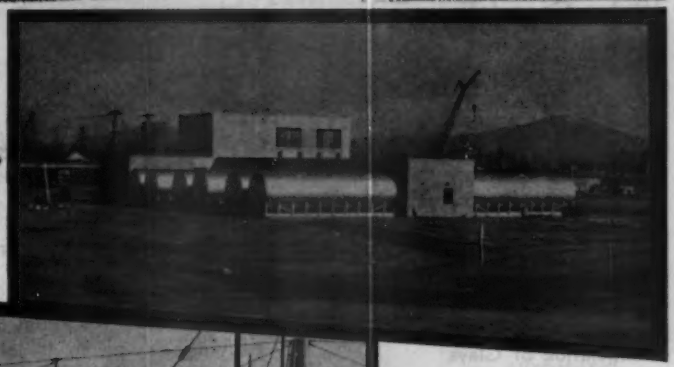

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icle constitute an ion-exchange system and an equilibrium exists between them and other ions in solution. This allows the substitution of the positively charged aluminum or ferric ions in the diffuse double layer surrounding the clay particle and, together with the number and size of the particles involved, governs the coagulant dosage.

Electrophoretic Studies of Water Coagulation

I will summarize recent studies of coagulation in which we have employed electrophoretic techniques to study the change in zeta potential of the floc particles. We studied coagulation for turbidity removal, the removal of organic color, and particle charge of the $CaCO_3$ and $Mg(OH)_2$ particles in the sludges produced in lime-soda softening.[34, 35, 36]

Coagulation of Clays

Three clays have been used for these studies. The first was a Kaolinite having a base exchange capacity of 8.7 microequivalents per 100 grams. The second, a Fuller's earth with a base exchange capacity of 26.5 microequivalents per 100 grams, and the last a Montmorillonite with a base exchange capacity of 115 microequivalents per 100 grams. Suspensions of each clay of about the same turbidity were prepared in distilled water containing 50 ppm of NaCl or $NaHCO_3$. The pH of the clay suspensions was adjusted with either HCl or NaOH as needed and jar tests run over the pH range 3.5-10.0 using 5 ppm, 15 ppm and 100 ppm of alum as the coagulant.

Particle mobilities were measured, using the Briggs cell as described in our previous paper. All clays were found to be negatively charged. The zeta potential of the particles was found to be dependent on the pH and on the alum dosage. An amount of alum equivalent to several times the base exchange capacity of the clay suspension was required to neutralize the particle charge. In general, clarification was best between pH 7.5 and 8.5 where the particles were negative rather than at pH values where the particle charge had been neutralized. Fair coagulation was often obtained below pH 4.5 where the particles were nearly neutral. In many cases, coagulation

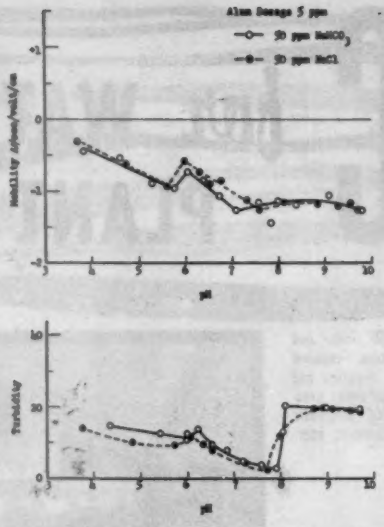

FIG. 2. THE EFFECT of pH on Mobility and Coagulation of Fullers Earth, (5 ppm of alum.)

changed sharply without any accompanying change in mobility values.

The data which follow show typical results for one clay at two different coagulant dosages. Figure 2 shows the residual turbidity and zeta potential of the floc particles when

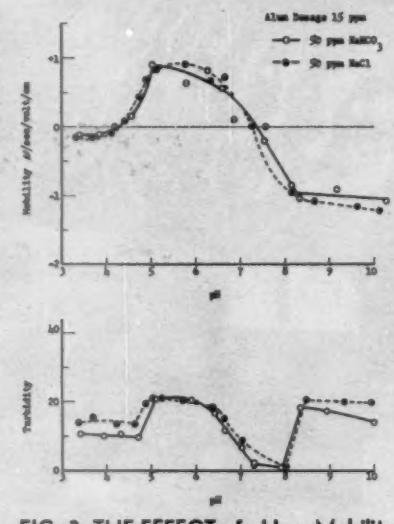

FIG. 3. THE EFFECT of pH on Mobility and Coagulation of Fullers Earth. (15 ppm of alum.)

a suspension of Fuller's earth was coagulated with a dosage of 5 ppm of alum. Figure 3 shows the corresponding curves when the alum dosage was increased to 15 ppm.

Before examining the curves it is important to know the relationships of the alum dosages added to the base exchange capacity of the clay suspension. The clay suspension had an exchange capacity of 19 microequivalents per liter. The dosage of 5 ppm of alum was equivalent to 45 microequivalents per liter and the dosage of 15 ppm of alum was equivalent to 135 microequivalents per liter. On Figure 2 it will be noted that although the alum dosage in microequivalents per liter was nearly three times the exchange capacity of the clay suspension, the excess was not sufficient to reverse the zeta potential of the clay particles which remained negative over the whole pH range 4 to 10 becoming more negative as pH increased, probably due to adsorption of hydroxide ions. Optimum coagulation at this dosage was in the range of pH 7.3 to 8.0 but it is important to note that this point can not be located from the curve of particle mobilities.

Figure 3 shows that with 15 ppm of alum particle charge was reversed from slightly negative to positive at about pH 4.2, remained positive throughout the pH range 4.2 to 7.2, beyond which it became increasingly negative. Evidently the seven-fold excess of aluminum ion in microequivalents over the base exchange capacity of the clay, also in microequivalents, was sufficient to bring about charge reversal, whereas the three-fold excess provided by the dosage of 5 ppm of alum was not. As in Figure 2, there was an acid zone of poor-to-fair coagulation but the zone of best coagulation was, as before, in the pH range 7.3 to 8.0.

While the particle charge throughout this zone was negative, it should be noted that the mobility curve does exhibit a sharp point of inflection within the zone of good coagulation which might possibly serve in practice to locate it.

The optimum coagulation of all clays was found to take place in the pH zone 7.5 to 8.5 and this is in agreement with Packham and his associates who found the same thing to be true of clay suspensions from nine English rivers. It is probably more than coincidental that most of the determined values for the isoelectric point of $Al(OH)_3$ fall within this pH range.

Eight coagulant aids were used in conjunction with alum in the coagulation of the Kaolinite. It was used because with its low base exchange capacity it was the most difficult of the three to coagulate. Some of the

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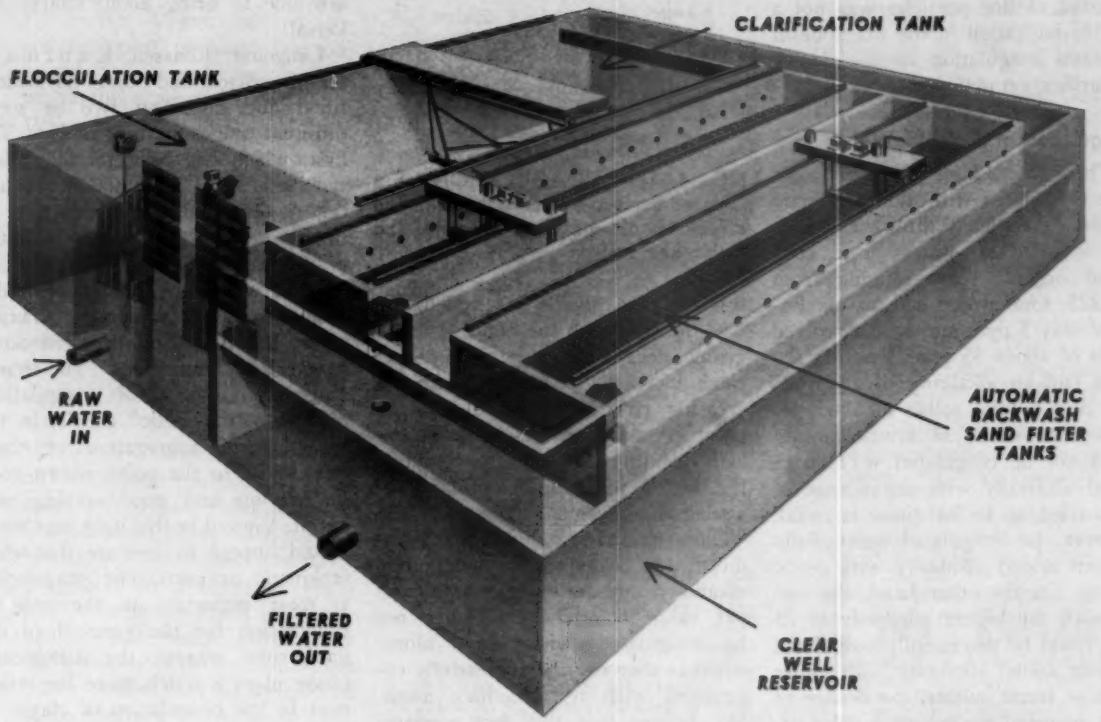

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aids studied were quite effective in producing better coagulation and larger flocs; some were relatively ineffective; and still others actually retarded coagulation. In no case could particle charge be correlated with a zone or zones of optimum coagulation.

From these studies we have concluded that, at least for the clays we used, measurement of the zeta potential of floc particles was not a reliable indication of the pH zone of optimum coagulation or the degree of clarification obtained.

Coagulation of Colored Waters

When waters high in organic color were coagulated with alum or ferric sulfate a completely different picture was found. The waters used contained organic color ranging from 200-225. One water had an alkalinity of only 5 ppm and total dissolved solids of about 35 ppm, whereas the other had an alkalinity of about 25 ppm and a total solids of about 90 ppm. The water of low alkalinity could not be coagulated without added alkalinity with any dosage of alum tried up to 500 ppm. It could, however, be coagulated successfully without added alkalinity with ferric sulfate. On the other hand, the water with the higher alkalinity of 25 ppm could be successfully coagulated without added alkalinity with either alum or ferric sulfate, the dosage of alum required for optimum color removal being approximately twice the dosage of ferric sulfate required.

Figure 4 shows the mobility of floc particles and residual color when coagulating the low alkalinity water with alum, the pH range being attained by the addition of gradually increasing dosages of lime. It will be noted that the floc particles were negative in the lowest acid range, became positive at about pH 4.5, and after reaching a maximum value again reversed charge and became negative at about pH 5.5, beyond which they became increasingly negative, probably due to adsorption of hydroxide ion.

The first point of charge reversal locates the beginning of the narrow pH zone of excellent color removal and the second point of charge reversal takes place at about the optimum pH for best color removal. Figure 5 shows the coagulation of the same water with ferric sulfate. In

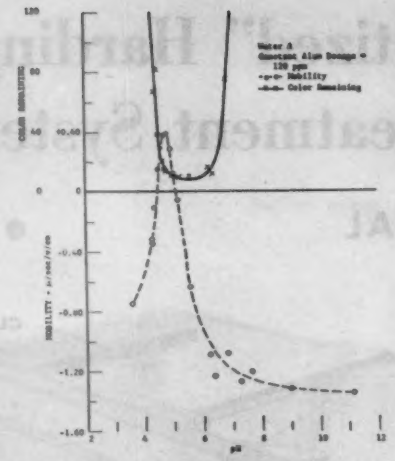

FIG. 4. THE COAGULATION of a Colored Surface Water with Alum. The Effect of pH on Floc Mobility and Color Removal.

this case no alkali was added. As was the case with the alum, the first visible flocs were negative and became increasingly positive with increasing coagulant dosage and the point of charge reversal almost exactly identifies the inflection point of the narrow pH zone of optimum coagulation.

To summarize, our studies indicate that below a certain minimum alkalinity and, of course, minimum pH value, colored waters may not be coagulated with alum alone, whereas they may be successfully coagulated with ferric sulfate alone. We believe that this fact confirms the work of Mattson[8] who pointed

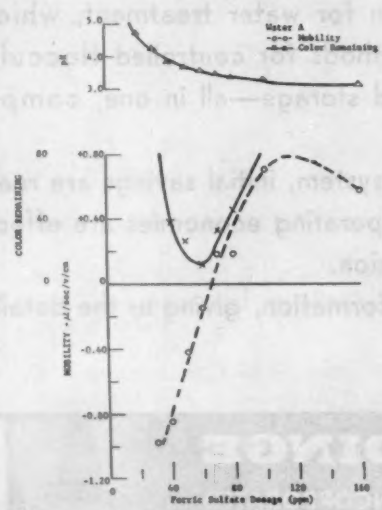

FIG. 5. THE COAGULATION of a Colored Surface Water with Ferric Sulfate. The Effect of Dosage on Floc Mobility, Color Removal, and pH.

out that the hydrolysis products of aluminum sulfate play a more important part in changing zeta potential than does the trivalent aluminum ion. At very low pH values alum does not hydrolyze sufficiently to form enough "basic sulfates" to be effective, whereas ferric sulfate does hydrolyze within this pH range and does provide these highly positively charged hydrolysis products which are able to bring about charge reversal.

Langelier, Eliassen, Kaufman, Nesbitt, Black, and others have identified and described two or more different stages in coagulation. The first, which has been termed "electrokinetic" or "perikinetic" coagulation is essentially the reduction or neutralization of the zeta potential of the particles being coagulated to a point where the London-Van der Waals attractive forces serve to bring about the formation of what some have called "micro-flocs." The second and third stages of coagulation, termed "orthokinetic" consist in the growth and aggregation of these micro-flocs to the point where good flocculation and good settling will result. Viewed in this light, our work would appear to indicate that electrokinetic or perikinetic coagulation is most important in the case of coagulation for the removal of organic color, whereas the orthokinetic phase plays a much more important part in the coagulation of clays.

Electrophoretic Studies

Black and Christman[36], using electrophoretic techniques, have determined the zeta potential of the sludge particles produced in the lime-soda softening of two synthetic waters. They found $CaCO_3$ to be negative and $Mg(OH)_2$ to be positive throughout the entire pH range of water softening. They found, however, that the zeta potential of $CaCO_3$ particles could be changed from negative to positive by a dosage of about 80 ppm of $MgCl_2$.

Conclusions

In the light of the observed behavior of both aluminum and ferric salts as coagulants in the removal of turbidity or organic color, with and without the addition of coagulant aids, one might be justified in drawing the following tentative conclusions.

1. In turbidity removal, the base exchange capacity of the clay is important and materially affects the coagulant dosage.
2. High base exchange capacity clays are easier to coagulate than are low ones and may be coagulated over a much wider pH range.
3. Clay turbidity is best removed by coagulation in the pH range 7.5 to 8.5. Values for the isoelectric point of alum floc obtained by several workers fall within this range.[37, 38, 39]
4. When both are expressed in microequivalents per liter, a concentration of aluminum ions many times the base exchange capacity of clay turbidity present is required for charge reduction or reversal.
5. Electrophoretic measurements of particle mobility and zeta potential are not a sure guide in indicating the behavior of a given clay with a given coagulant.
6. While the chemical composition of the organic compounds which constitute organic color in water is not known, these materials behave toward aluminum and ferric coagulants as if they are negatively charged colloids. The following statements characterize the behavior of these color bodies in the case of two highly colored surface waters.
   a. The relatively narrow zone of good coagulation and low residual color is accompanied by reversal of the zeta potential of the floc particles from negative to positive.
   b. The hydrolysis products of aluminum and ferric sulfates appear to be more effective than the trivalent cations in reducing or reversing the zeta potential of the colloidal color particles.
   c. Correlation between the coagulation curves and electrophoretic data was excellent.
7. For the removal of either turbidity or organic color, the coagulant dosage and the mode of action are dependent upon total dissolved solids and the nature of other ions present and it is this fact which accounts for the individuality of different waters.
8. Coagulation, with or without the use of coagulant aids, is a complicated process involving, among other things:
   a. Reduction or reversal of the zeta potential of the particles to be removed.
   b. Electrostatic cross-linking involving polyvalent ions.
   c. Hydrogen bonding.
   d. Adsorption.

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SETTLING BASIN DETENTION TIME TEST*

by JAMES HORNUNG

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This paper describes a test to determine the detention time in a settling basin. In addition, this test was conducted to compare the use of sodium chloride versus free chlorine as indicators in basin flow tests and determine if the testing method applied to a basin flow initially in motion would differ from one not initially in motion. The centers of moments determined in this test indicate that there is a significant difference.

The water plant at Holland, Michigan offers a unique opportunity to apply both the sodium chloride and free chlorine methods simultaneously. This plant uses a hydraulic jump for the rapid mixing of chemicals. In this, the raw water takes a 2.5 ft vertical drop to the water level in a four by six foot flume when pumping at a rate of five mgd. The flume has a depth of 12 ft below the overflow level of the settling basin and is connected to the basins by a 36 in. line about 200 ft long. The mix appears to be very effective. The settling basins are equipped with flocculators, collecting weirs and a baffle wall. A sample pump continuously delivers samples from a 54 in. line leading to the filters from the basin. This was the sampling point for these tests. These tests were run with a single basin having a theoretical detention time of six hours.

Procedure

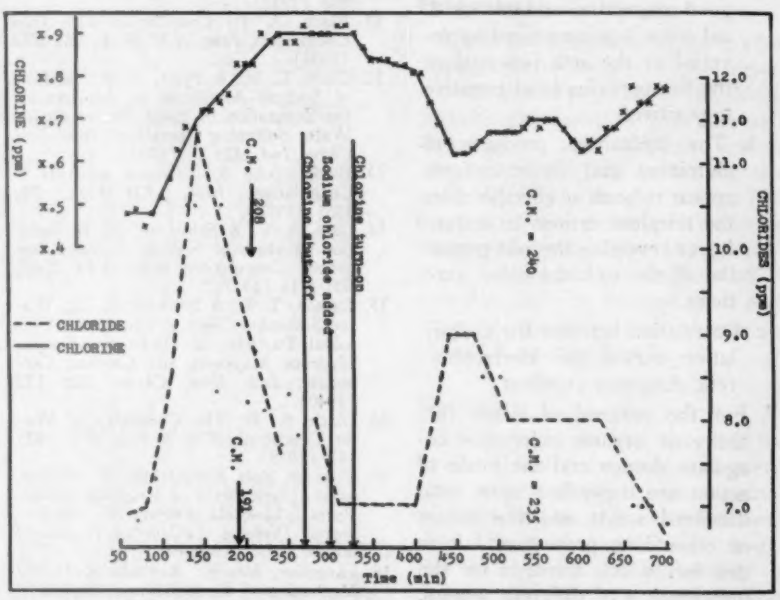
The simultaneous tests were run in the following manner; the plant was shut down and the vertical mixing flume was dosed with 50 lbs of dissolved sodium chloride and a strong chlorine solution. Pumping was then started at a rate of five mgd through the plant and a high chlorine dose was maintained. Chlorides and free chlorine residuals were then run from the basin effluent, which was sampled every 10 minutes. After 270 minutes the chlorine dose was stopped for exactly one hour. In the middle of this chlorine shutoff (at 300 minutes) another dose of sodium chloride was added instantaneously. This part of the test was run to determine if there would be a difference in pattern between a basin that was not initially in motion and one that was in motion. The concentrations of chemicals during significant periods of the test are shown in the graph.

The centers of moments for the period 80 to 310 minutes are 191 minutes for chlorides and 208 minutes for free chlorine. During the period 400 to 680 minutes the centers of moments for chlorides is 535 minutes and for free chlorine 540 minutes. Since the dosing time for the period 400 to 680 was at 300 minutes, the centers of moments from this point are actually 235 and 240 minutes.

It is interesting that the two curves are almost mirror images during the period 400 to 680 minutes, yet the actual period of dose change for chlorine was 60 minutes, while the chloride was added in a few seconds. Also, the time from the chlorine shut-off to a drop in concentration was 120 minutes, while the time for chlorine turn on to concentration increase was 270 minutes.

Chlorine residuals were run with a photometric instrument and chlorides were determined with silver nitrate. Both methods showed excellent reproducibility.

The author acknowledges the help and efforts of G. Goshorn, L. Martin, J. VanDeWege, R. Boere and J. Palecek.



CONCENTRATIONS OF CHEMICALS during significant periods of the test.

*"This is one of the papers presented at the Short Course on Coagulation of Water for Filtration, conducted at The University of Michigan, Feb. 9-10, 1961. All of the papers presented are included in the course Proceedings, which is available through the Continued Education Service, School of Public Health, The University of Michigan, Ann Arbor."

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SEDIMENTATION*

BY S. B. MAYNARD

Ayres, Lewis, Norris & May, Consulting Engineers, Ann Arbor, Mich.

■ Sedimentation as practiced in water treatment plants has the purpose of separating solid suspended particles from the water being treated. The objective is, of course, to supply an effluent water suited to further treatment if from a primary basin, or to final clarification by filtration if from a final tank. A turbidity of 1.5 ppm may be considered to be a desirable standard for water applied to the filters.

Design

Several elements enter into the design of a sedimentation tank. The effectiveness of pretreatment and flocculation will have a large influence on the successful operation of the settling tanks in the accomplishment of separation of the solids from the liquid.

The sedimentation process is related basically to the "Stokes" relationship with respect to settling velocities of a particle in a fluid. An excellent discussion of this has been provided by Camp.[1]

The fact that particles tend to settle in still water at a velocity compatible with the basic conditions is not the complete story. The settling velocity must be correlated with the fluid velocity. If the fluid is in motion, the suspended particle, in addition to its settling velocity, will have a velocity which is of magnitude and direction of the motion of the fluid medium. Therefore, a component of motion in an upward vertical direction will reduce the downward velocity of the particle, while in the downward direction it will increase the settling velocity. The particle will be given a horizontal motion in accord with the horizontal component of the fluid flow. The resultant velocity and direction of particle movement will be the summation of the velocity and direction component of the particle and the fluid.

Understanding that the currents generated in the settling basins may have a marked effect on performance, and that beyond proper pretreatment there is little possibility to vary the sedimentation law relationships, we must give more thought toward improvement of the basin.

The design of a sedimentation tank should attempt to control the currents generated that they will not defeat the purpose. Currents should be maintained at low velocity levels with the flow distributed uniformly over large areas. This concept is exemplified in the design factors of flow-through time, overflow rate, retention time, and efficiency.

Rectangular Tank

The rectangular tank is arranged for a uniform velocity, straight line, horizontal cross flow, it being assumed that the particles in suspension will settle to the bottom before arriving at the end of the tank. The specific design factors are concerned with minimum settling velocity and maximum horizontal velocity, the resultant velocity vector terminating at the tank bottom near the outlet end for particles originating near the water surface. The maximum quantity of flow divided by an allowable average velocity of horizontal flow defines the cross section area of the flow channel. These factors are related in the simple formula $Q = AV$.

Two other factors, retention time and overflow rate, are also included to define the tank proportions. Overflow rate is the flow quantity divided by the water surface area and may be stated as gallons per square foot per day. Surface loading is used to express the same function of overflow rate. An overflow rate up to 700 g/sq ft/day is frequently used with an alum floc, while up to 1600 g/sq ft/day may be used with a lime floc, and up to 1200 g/sq ft/day with a magnesium floc. The retention time is defined as the time required to fill the tank at a given rate of flow.

Camp, in his paper, presents the thesis that the removal of solids is a function of the overflow rate and is not dependent on the retention time. Retention times of approximately four hours for alum floc, three hours for magnesium and two hours for calcium carbonate flocs are used. If the retention volume is divided by the surface area, the result will be feet of depth. Presuming a tank to be designed for alum floc at a flow rate of 10 mgd and four hour retention time, the required volume will equal $10/24 \times 4 = 1.667$ mg which, in turn, equals $1.667/7.48 = 223{,}000$ cu ft. Using 700 g/sq ft/day overflow rate, the surface area required is $10 \text{ mg}/700 = 14{,}300$ sq ft and the tank depth required is $223{,}000/14{,}300 = 15.6$ ft. The length and width of tank are not subject to calculation directly except as a limitation of horizontal velocity is imposed, thus if horizontal velocity is limited to ½ ft/min the resultant length of tank will be $240 \text{ min} \times ½ \text{ ft/min} = 120$ ft.

Noting the depth of tank which results from these computations one is tempted to ask why not reduce detention time and depth? But, presuming the bottom ⅓ of the tank

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capacity were removed, the resultant horizontal flow velocity would be 1.5 times the initial velocity. Consider also that the greater the velocity of flow, the greater the energy imparted to the fluid, in accord with the relationship $V^2/2g$, and the greater the possibility of differential flow and eddy currents.

The hydraulic efficiency of the basin may be defined as the actual time required by an input fluid element to traverse the tank, divided by the retention time. If short circuit currents are present, efficiency may be of the order of 33 to 60 percent.

Circular Tank

The circular and/or center inlet settling tanks for horizontal flow are similar to the rectangular tank, except that lineal flow is no longer uniform and the retardation of horizontal flow is accompanied by a lateral displacement of fluid particles. It is logical to assume that the effect of the reduced horizontal velocity is to develop a zone of more nearly quiescent settling.

With respect to these tanks, using the same data as used above:

$$\text{Retention volume} = \frac{10\text{mg}}{24} \times 1.66\text{mg}$$

$$\text{Surface area} = \frac{10\text{mg}}{700} = 14{,}300 \text{ sq ft}$$

$$\text{Depth} = \frac{1{,}660{,}000}{7.48 \times 14300} = 15.5 \text{ ft}$$

$$\text{Circular tanks: radius} = \sqrt{\frac{A}{\pi}} =$$

$$\frac{14300}{3.1416} = 77 \text{ ft and diameter} = 154 \text{ ft}$$

$$\text{Square tank: side length} = \sqrt{A} =$$

$$\sqrt{14300} = 120 \text{ ft}$$

Vertical Flow Tank

The upward flow tank design is based upon the same fundamentals of hydraulic flow which we have been discussing. These units are principally used in combination with coagulation or chemical reaction compartments and utilize an upward flow velocity through a region of concentration, or recirculation and remixing of the reaction products.

The settling compartment is usually constructed with sides sloping outward and upward causing the velocity to be continually decreasing as it progresses upward. In the manner there tends to be a graduation of size of particles suspended in the upward flow, each particle balancing where its settling velocity is balanced by the upward component of velocity.

Concentration of particles is such that they interfere one with another in settling. Thus the entire collection of solids tends to settle at a uniform rate. At the separation plane it is probable that when a particle settling velocity is exceeded by the rising velocity, the particle is trapped in the rising current. Where the upward flow velocity is compatible with the settling rate of the sludge blanket, the water will tend to separate without entrapment of sludge particles. However, there must be a limiting overflow rate for tanks of this design. This rate must be less than the settling velocity of the smallest size of particle of least density for which the tank is designed. The selection of proper overflow rate is more critical perhaps for this design of tank than the horizontal flow tanks.

An overflow rate of 700 g/sq ft/day represents a rising velocity of:

$$\frac{700}{7.48 \times 1440} = 0.065 \text{ ft/min}$$

The fact that average velocities cannot be maintained because the area and location of collection facilities is not uniform over the surface indicates that actual rising velocities to tank outlet must be greater than above computed.

Inlets and Outlets

It is evident, therefore, that the inlet and outlet elements of sedimentation tanks may have a material effect upon the functioning of the tanks. If the inlet and/or outlet designs are such as to concentrate flow in areas less than the cross section area of the flow channel, there must be an increase in velocity in the area of concentration. At the inlet end, a concentration of flow may create a short circuiting current which, depending on its vertical location and strength (or velocity), may materially upset the settling process. Likewise, if the influence of the outlet to increase flow velocity causes increased velocity or upward velocity before the final sedimentation has occurred, the efficiency of the basin will be reduced.

Inlet

Many arrangements of tank inlets have been attempted. In principle, the inlet should be arranged to equalize the distribution of the inflowing water across the entire cross section of the flow channel. It should have only enough restriction to maintain the distribution of flow, and a minimum inlet velocity. Thus a stilling area and multi-port screen might be a suitable inlet.

In circular tanks with center inlet, a stilling well and distributing vanes are most frequently employed, arranged either for radial flow or to generate a spiral flow. The point of input flow is normally in the upper part of the tank.

The vertical flow tanks are normally arranged with a central mixing compartment and a settling compartment. The slurry is introduced in the lower level of the tank and the rising velocity of the water suspends the slurry and tends to classify it by particle size. These basins, in the writer's opinion, are sensitive to changes of flow and slurry condition and are less suited to widely varying conditions.

A different condition is noted in the instance of the Accelator* where the inlet flow to the settling compartment is horizontal at the approximate level of the top of the slurry. The solids are not, therefore, supported by a rising flow but are allowed to settle aided by a recirculation draft from the bottom level of the tank. The separation of the clear water from the slurry may occur naturally at the top level of the slurry.

Outlet

The outlet of the sedimentation tank is perhaps more critical to the proper functioning of the tank than any other single element. Many rectangular tanks employ weirs discharging to collection channels. Their length may be increased by overflow on two sides of the collecting channel or through the use of multiple collection channels. Whatever the situation, the approach velocity to the weir is increasing and tends to give the effect of short circuit currents. The use of a multiple submerged orifice may have a similar effect, the seriousness of which may be proportional to the change of

*Product of Infilco, Inc., Tucson, Arizona.

velocity of the liquid in passing through the orifice. It is of importance with alum floc that there be as little disturbance in the fluid as is feasible. While not knowing of a specific instance, it would seem logical to the writer to install a multiple slot or multiple port baffle wall ahead of the outlet collection channel as a flow distribution control device.

In center inlet tanks having horizontal flow, the outlet is most frequently either straight edge or multiple V notch. The weir serves the secondary purpose of determining the water level in the tank. Multiple submerged orifices may likewise be used in control of distribution of radial flow. Such collection channels are normally at the upper periphery of the tank. It is usual that the weir will be longer in this type of tank than in the rectangular tank and the deleterious effects may be partially limited by this factor.

The upward flow tank is frequently designed with collection troughs distributed over the surface area, providing long weir lengths and uniform distribution of the vertical flow. It is still believed by the writer that the overflowing weir type of collection device may be improved upon to reduce the maximum velocity experienced at the weir crest.

Other Factors

For sludge removal from settling tanks, the rectangular horizontal flow tank may be arranged with hopper type bottom for intermittent flushing, or they may be provided with continuous mechanical flight scrapers. Continuous chain scrapers have been installed with counterflow collection of sludge toward the inlet end of the tank and having the bottoms slightly sloped to the inlet for drainage purpose. A collection of sludge in the direction of flow would seem to be advantageous in the minimizing of eddys and disturbance of flow. Movable bridge mounted scrapers are available and may be used in intermittent cleaning operation.

Circular or square settling tanks are equipped with rotating bridge arms having scraper blades arranged to move the settled sludge to a sump or sumps adjacent to the center support for the mechanism. Rotational velocity is maintained to very low speed.

One further topic may be introduced into the discussion, being that of housing sedimentation tanks. An open tank is subject to various disturbances from the elements: temperature differences; the effect of winds in the generation of eddy currents and wave action; and lack of protection from animal and vegetable matter.

A cover close to the water surface will accomplish many of the objectives of a superstructure but usually makes maintenance operations more difficult and reduces visual observation of actions taking place in the basin.

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SETTLING BASIN EFFICIENCY TESTS*

by Dr. A. M. SHANNON

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■ The Springwells Filtration Plant consists of three separate and distinct water treatment plants. The original plant was placed in operation in 1932 and two smaller parallel plants were added in 1959. These plants receive the same raw water and have the same chemical treatment, consisting of chlorine, carbon and alum.

The rated capacity of the older plant is 272 mgd and that of the addition is 180 mgd, a total of 452 mgd. For peak demand periods, a total of 540 mgd can be produced.

The original Springwells plant is not equipped with mechanical rapid mix or mechanical flocculators. The mixing basin is 75 ft. wide and 335 ft. long and has around-the-end baffles to increase the mixing efficiency. There are four settling basins, and each one is 340 ft. long, 135 ft. wide and has an average depth of 18 ft. Water flows from the mixing basin through a lower conduit which extends the width of the basins. The flow divides and rises at two points into two conduits with each distributing the water across two settling basins. The inlet structure of each consists of 17 vertical slot openings, each 12 in. wide. There are seven straight vanes extending 29 ft. into the basin to direct the flow. At the end of the settling basins, the water flows over weirs into a collecting channel to the filters. The detention time is 2.2 hours at a 272 mgd flow.

The Springwells Addition is equipped with mechanical rapid mix, flocculators in compartments to prevent short-circuiting, and a perforated baffle wall between the flocculators and settling basins. There are 20 flocculator chambers and 4 settling basins, each 484 ft. long, 100 ft. wide, with an effective water depth of 13 to 17 ft. The detention time is 3.2 hours at 180 mgd rate.

The pre-treatment results of the original Springwells Filtration Plant indicated short-circuiting through the settling basins. Accordingly, it was decided to determine the settling basin efficiencies at low and high rates for the following reasons:

1. They show whether the settling basins are functioning properly.
2. They point out short-circuiting, which curtails the settling of coagulated matter.
3. They suggest improvements in existing basins.
4. They aid in the design of future basins.

Terminology

The detention period is defined as the time required to fill a basin at a given rate of flow. It is also the volume of the basin divided by the rate of flow. This is a theoretical figure which cannot be used for the actual flow through a basin.

The term "flowing-through period" was coined by C. G. Hyde of the University of California who defined it as the average time required for a small volume of water to pass through a basin at a given rate of flow.

The displacement efficiency as applied to settling basins is defined as

$$\text{Efficiency} = \frac{\text{flow-through period}}{\text{detention period}} \times 100$$

From these definitions it is apparent that the most efficient basin, so

Table I

Typical Data Sheet

Mixed Water (influent) time	chlorine residual ppm	(I=0.40) C—I ppm	Settled Water (effluent) time	chlorine residual ppm	(I=0.30) C—I ppm
12:00 N	0.40	0.00	12:40 pm	0.30	0.00
12:05 pm	0.40	0.00	12:50 "	0.30	0.00
12:10 "	0.40	0.00	1:00 "	0.30	0.00
12:15 "	0.40	0.00	1:10 "	0.30	0.00
12:20 "	0.40	0.00	1:20 "	0.30	0.00
12:25 "	0.45	0.05	1:30 "	0.35	0.05
12:30 "	0.60	0.20	1:40 "	0.40	0.10
12:35 "	0.90	0.50	1:45 "	0.45	0.15
12:40 "	0.90	0.50	1:50 "	0.50	0.20
12:45 "	0.90	0.50	1:55 "	0.50	0.20
12:50 "	0.90	0.50	2:00 "	0.50	0.20
12:55 "	0.80	0.40	2:05 "	0.55	0.25
1:00 "	0.60	0.20	2:10 "	0.60	0.30
1:05 "	0.50	0.10	2:15 "	0.60	0.30
1:10 "	0.50	0.10	2:20 "	0.50	0.20
1:15 "	0.45	0.05	2:25 "	0.50	0.20
1:20 "	0.45	0.05	2:30 "	0.50	0.20
1:25 "	0.45	0.05	2:40 "	0.45	0.15
1:30 "	0.45	0.05	2:50 "	0.45	0.15
1:40 "	0.45	0.05	3:00 "	0.40	0.10
1:50 "	0.45	0.05	3:10 "	0.40	0.10
2:00 "	0.45	0.05	3:20 "	0.40	0.10
			3:30 "	0.40	0.10
			3:40 "	0.40	0.10
			3:50 "	0.40	0.10

Coagulation Basin 2
Rate: 195 mgd
Elevation of water in basin: 130.1 ft
Water temperature: 35° F

C = chlorine residual in ppm at each sampling time
I = initial chlorine residual in ppm at the begininng of each run

*"This is one of the papers presented at the Short Course on Coagulation of Water for Filtration, conducted at The University of Michigan, Feb. 9-10, 1961. All of the papers presented are included in the course Proceedings, which is available through the Continued Education Service, School of Public Health, The University of Michigan, Ann Arbor."

far as complete utilization of its settling capacity is concerned, will be one in which the ratio of the flowing-through period to the detention period is unity.

E = Efficiency rating in percent
F = Flowing-through period in hours.
D = Detention period in hours
C = Capacity of basin in gallons
Q = Rate of flow in gallons per day

$$D = \frac{C}{Q} \times 24$$

$$E = 100\,\frac{F}{D} = \frac{100\,F}{\frac{C \times 24}{Q}} = 4.17\,\frac{FQ}{C}$$

The experimental tests required to solve the above equation consists of determining the flowing-through period for a basin at a specific and constant rate of flow.

Method

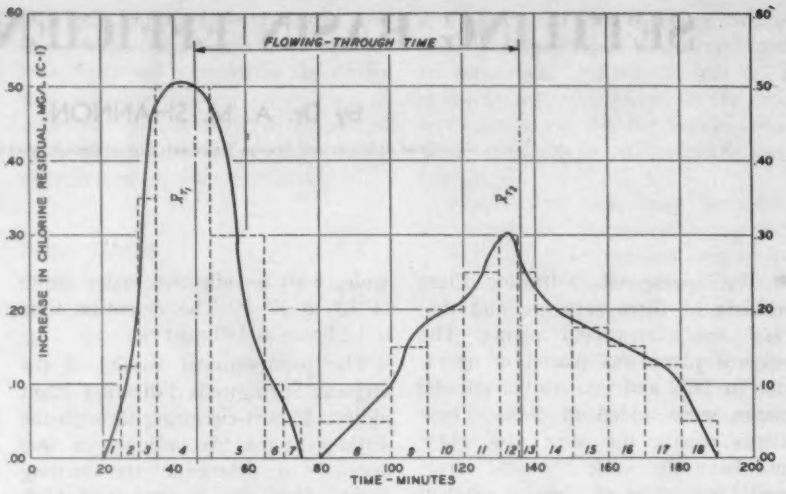
The method used at the Springwells Plant consisted of increasing the pre-chlorine dose for 15 min. and then measuring the variation in chlorine residual at the influent and effluent ends of the basins.

Other chemicals, such as sodium chloride, alum and dyes, can be used. We chose chlorine for the following reasons: 1. it was necessary for the water being measured to pass directly to the distribution system; 2. it was easier to apply the large dosages necessary; and 3. the chlorine residual test is simple, fast and accurate.

Chlorine residuals were measured at both ends of the basin at five minute intervals until the residuals returned to normal. This indicated the increased dosage had passed the sampling points. Chlorine residuals were determined by the ortho-tolidine arsenite method using a photo-electrical colorimeter.

A typical data sheet showing the various readings is given in Table 1. The increase in chlorine residual over the normal is also shown. Using these data, a graph of the increase in chlorine residual versus time was constructed. The graph was composed of two areas; influent and effluent. A typical graph is shown in Figure 1.

By the method of moments and applying graphical integration, the center of gravity of each area was calculated, the time corresponding to these points was determined and the difference between the influent and effluent times was designated the flowing-through period. Using this flowing-through period and substituting in the equation, the displacement efficiency of the basin was calculated.



TYPICAL GRAPH of influent and effluent areas, taken from coagulation basin 2.

The theoretical basis for using the center of gravity of each area rather than the line which bisects each area is treated in the *A. W. W. A. Manual*, "Water Quality and Treatment," page 180.

Results

As was stated before, the Springwells settling basins consist of two inlets. Basins 1 and 2, operating in parallel through a common inlet, form one unit, and basins 3 and 4, operating the same way, form the other. Water for both units is supplied from a single conduit from the mixing basin.

Table 2

Results Obtained During Low and High Pumpage Rates

Rate mgd	Basin Number	Flowing-Through period (hours)	Basin Efficient percent
195	1	2.0	63.9
195	2	1.5	50.8
195	3	2.1	67.6
195	4	1.7	54.0
325	1	0.95	51.5
325	2	1.1	58.2
325	3	—	—
325	4	0.9	45.7

Table 2 tabulates results obtained from tests run during low and high pumpage rates. It was found that basins 2 and 4 were less efficient than basins 1 and 3. This was due to the design of the basins. The velocity and flow at each common inlet was such that the tendency was to put more water through basins 2 and 4 than through basins 1 and 3. This greater velocity decreased their efficiency.

It was possible to alleviate this condition for basins 1 and 2 at high pumpage rates by opening a sluice gate that permitted water to flow directly from the mixing basin into basin 1. This by-passed the common inlet with basin 2. Results indicated that this remedied the discrepancy somewhat. In fact, the basin efficiencies were reversed with basin 1 becoming less efficient. However, the difference was much less than under normal operating conditions.

It was impossible to effect the above remedy with basins 3 and 4. Test results on basin 4 show the decrease efficiency of this basin at the higher rates. Since the effluents from basins 3 and 4 are near a common outlet, the high velocity through basin 4 caused some of the outlet flow to swing over into the outlet from basin 3. It was difficult to obtain reliable samples. No difficulty was experienced testing basins 1 and 2 which have an identical outlet.

A similar survey made on the Springwells Addition showed settling basin efficiencies of 90 percent.

COMMON CHEMICALS USED IN COAGULATION*

BY JAMES C. VAUGHN

Chief Filtration Engineer, South District Filtration Plant, Chicago 49, Ill.

■ The history of coagulation and coagulants has been very well covered in the literature. It is the purpose of this discussion to describe the coagulants now in use, their apparent reactions, choice for specific purposes and the advantages and disadvantages of each.

Alum

"Hoover Process" Alum

Charles P. Hoover patented the digestion of bauxite with sulfuric acid and the addition of the resultant liquor directly to the water being treated, without settling or adjustment of the free acidity. This was one of the earlier liquid feeds.

"Activated" Alum

This brand of alum retains the insoluble material normally settled out, plus some silica, and has less molecules of water of crystallization than regular alum.

"Black" Alum

This is regular filter alum to which has been added 2 to 5 per cent activated carbon, for taste and odor removal. Independent control of alum and carbon dosages is not possible.

"Lump" Alum

Regular filter alum, after crystallization but before grinding and screening, was at one time obtainable in bulk at a somewhat lower price than regular alum.

Regular or "Filter" Alum

The American Water Works specification (B-403-54) for this material is:

Alumina —(not less than 17 per cent as Al_2O_3 available water soluble alumina.)

Iron —(not more than 0.75 per cent)

Basicity —(at least 0.3 per cent of Al_2O_3 over SO_3 present)

Insolubles (unpurified alumina —not more than 10 per cent)
(purified alumina—not more than 0.5 percent)

It is available in bags or bulk and is usually fed on a dry weight basis, being put into solution following the discharge from the weigh belt. Dosages vary from 5 to 40 ppm based on the formula of $Al_2(SO_4)_3$ —17 H_2O with occasional dosages as high as 70 ppm.

Alum Solution

Alum liquor taken from the process of regular alum manufacture just prior to evaporation, known as alum solution, or "liquid" alum. It contains approximately 5 lbs/gal of $Al_2(SO_4)_3$—17 H_2O and weighs about 11 lbs/gal. It is sometimes referred to as 50 per cent alum as it contains approximately 8.5 percent Al_2O_3 as compared with the 17 per cent Al_2O_3 content of "dry" alum. Clear amber liquid with a specific gravity of 1.324 ± 0.008. It can be obtained in tank cars or tank truck. This alum solution crystallizes at approximately 5°F.

The system for handling alum solution may be briefly described as follows: The material on receipt is unloaded by gravity into lead-lined concrete tanks. From these tanks it is pumped to plastic-lined concrete tanks (old dry alum bins). From this point the solution flows by gravity to feeders. If alum is being fed to more than one basin the discharge is diluted and fed to a weir box where it is divided into equal flows for the number of basins to which alum is being applied.

Sodium Aluminate

The A.W.W.A. tentative standards (B405-59T) states:

"The solid form is a white or brown powder containing 70-80 per cent $Na_2Al_2O_4$; the solution form is a concentrated solution containing approximately 32 per cent $Na_2Al_2O_4$.

"Solid sodium aluminate shall contain a minimum of 75 per cent available soluble $Na_2Al_2O_4$."

Either the solid or liquid material may be fed by the proper type of conventional chemical feeder.

Iron Salts

Ferric Sulfate: Two brands of ferric sulfate were at one time available. Ferrisul ise made from the iron oxide residue left from roasting iron sulfide in the old lead-chamber process of manufacturing sulfuric acid. Ferrifloc is made from iron oxide obtained by electrostatic precipitation of stack fumes from a low-grade copper ore smelter. The ferric sulfates are usually between 60 and 90 per cent $Fe_2(SO_4)_3$. The particle size is variable but should be such as to feed freely. (A.W.W.A. specification, 95 per cent should pass a 4-mesh screen and 100 per cent should pass a 3-mesh screen.) Warm water must be used to obtain complete solution. Dry ferric sulfate is sufficiently hydroscopic as to require protection from moisture for prolonged storage. The ferric sulfate solution requires non-corrodible tanks and lines for feeding.

Ferric Chloride: This may be obtained as 60 per cent $FeCl_3$ crystals ($FeCl_3$-$6H_2O$), as 98 per cent anhydrous $FeCl_3$ or as 39-45 per cent liquid $FeCl_2$.

Ferrous Sulfate or "Copperas": Ferrous sulfate sometimes known as "Copperas" is obtainable as $FeSo_4$-$7H_2O$ and $FeSO_4$-$5H_2O$ in the dry form. Crystals formed by the $FeSO_4$-$7H_2O$ formulation showed less tendency to cake or harden on storage. This material however, produced a dust hazard that resulted in many eye injuries. Dry ferrous sulfate is bluish-white material that is relatively non-corrosive and may be fed with the commercial dry chemical feeders. It may be fed in combination with lime but is usually, after dissolv-

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ing, oxidized to the ferric form with chlorine.

Ferrous Sulfate Solution: The principal source of the dry ferrous sulfate is the "pickling" liquor from the steel industry. The dry material prepared by evaporating this liquor contains approximately 21 per cent water soluble available iron.

In recent years the steel industry has made available the ferrous sulfate solution at the point just ahead of evaporation. This solution usually contains 7 per cent of water soluble available iron. The percentages of insoluble material and free acidity are in proportion.

The price of the ferrous sulfate in solution form is comparable to that of the dry ferrous sulfate.

It is necessary to write specifications and make tests to insure the absence of heavy metal contaminants, such as lead, nickel, chromium, manganese, or other contaminants that might be objectionable in a public water supply.

Lime

Lime is generally available in two forms: quick lime and hydrated lime. Quick lime is available in various sizes according to how it is to be handled. The A.W.W.A. specifications state that lime is to be fed on a dry-feed machine, none shall be retained on a ¾-in. sieve. If it is to be handled by a pneumatic conveying device, none shall be retained on a 1-in. sieve and not more than 10 per cent on a ¼-in. sieve. If the quick lime is to be handled by a mechanical conveying equipment, the pieces shall be no longer than 2-in. in size, except that an occasional slablike piece may be up to 3-in. in length. Not more than 20 per cent shall pass a ¾-in. sieve and not more than 10 per cent shall pass a ¼-in. sieve. Hydrated lime shall be white, dry, finely powdered, and free from lumps and any foreign material which may interfere with the operation of dry-feed equipment. Uniformity of particle size is a desirable characteristic.

Reactions

Aluminum Sulphate

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 = 2Al(OH)_3 + 3CaSO_4 + 6CO_2$$

$$Al_2(SO_4)_3 + 3Ca(OH)_2 = 2Al(OH)_3 + 3CaSO_4$$

$$Al_2(SO_4)_3 + 3Na_2CO_3 + 3H_2O = 2Al(OH)_3 + 3Na_2SO_4 + 3CO_2$$

Sodium Aluminate

$Na_2O : Al_2O_3$ or $Na_2Al_2O_4$ produces

$$R(HCO_3)_2 + Na_2Al_2O_4 = RAl_2O_4 + Na_2CO_3 + H_2O + CO_2$$

R = either Ca or Mg

Ferrous Sulphate

$FeSO_4 . 7H_2O$ reacts—

$$FeSO_4 + Ca(OH)_2 = Fe(OH)_2 + CaSO_4$$

$$4Fe(OH)_2 + O_2 + 2H_2O = 4Fe(OH)_3$$

Ferric Chloride

$FeCl_3 . 6H_2O$ reacts—

$$2FeCl_3 + 3Ca(HCO_3)_2 = 2Fe(OH)_3 + 3CaCl_2 + 6CO_2$$

$$2FeCl_3 + 3Ca(OH)_2 = 2Fe(OH)_3 + 3CaCl_2$$

Chlorinated Copperas

$$6FeSO_4 + 3Cl_2 = 2Fe_2(SO_4)_3 + 2FeCl_3$$

The chemical reactions of the various coagulants are written in equation form. These equations represent the end product of the reaction of the coagulant with the alkalinity and/or mineral matter in the water. There are many possible interpretations of the intermediate reactions. No attempt is made here to express the reaction between aluminum sulfate and colloidal or color-producing substances in the water. Some investigators believe this to be an ion-exchange phenomena. The reaction of sodium aluminate with colloidal clays of volcanic origin in soft, low pH waters, is understood to be of a similar nature.

The earlier users of ferrous sulfate used it with lime with considerable success. The dissolved oxygen in water acted to convert the ferrous hydroxide so formed to the insoluble ferric form. The reactions of ferric chloride are rather obvious and produce the expected insoluble ferric hydroxide.

It is the oxidation of ferrous sulfate to ferric iron that creates a difference of opinion. The theoretical ratio of ferrous sulfate to chlorine based on molecular weight is 7.8 to 1. In actual practice this ratio seldom prevails. The factors of time, temperature, and mass-action effects come into play. At the South District Filtration Plant, the time factor has been altered by increasing the retention time in the oxidizing chambers, to three times that of the original installation. The mass-action effect is recognized by adding the chlorine intended for sterilization purposes, with that added for the purpose of oxidizing the iron. Not much can be done about the temperature effect beyond adjusting the time factor.

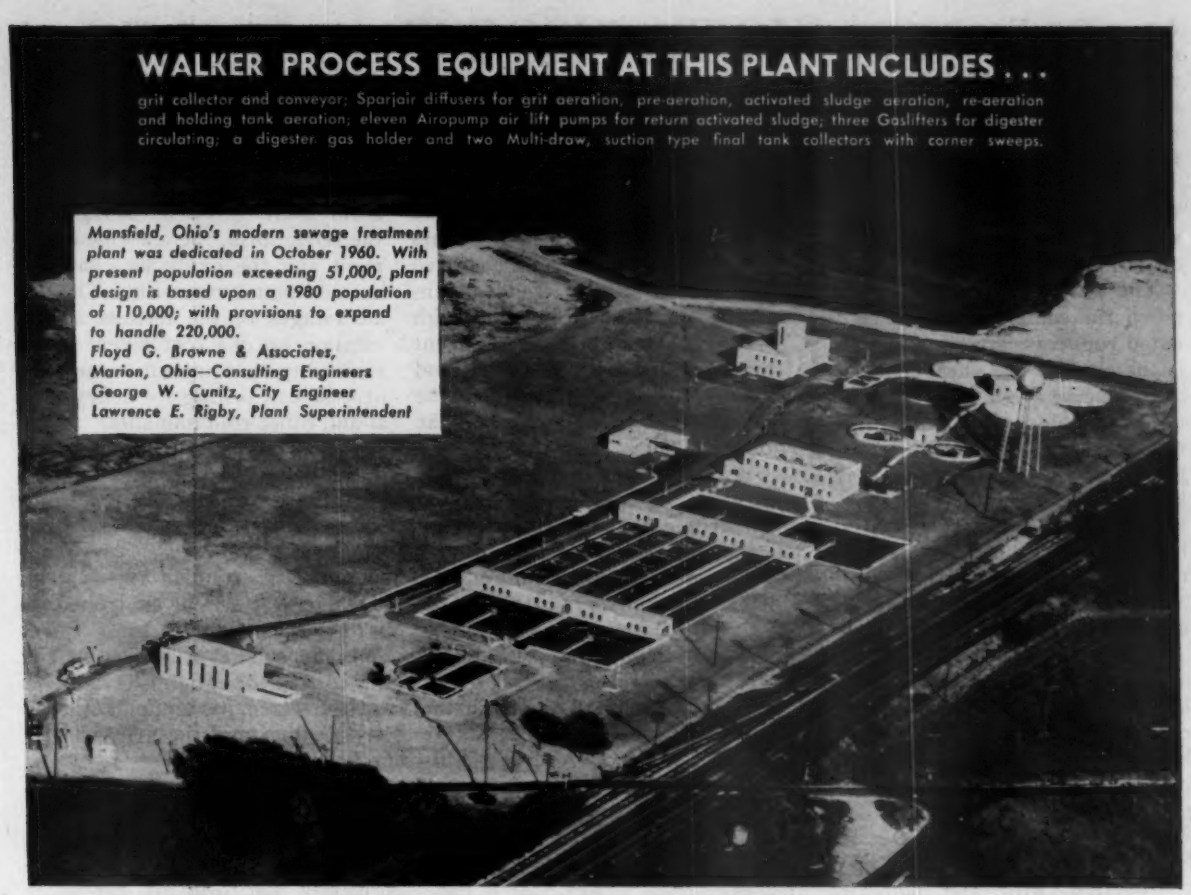
Lake Michigan water at Chicago ranges from 32°F. to 72°F. The ferrous sulfate chlorine ratio has ranged from 4 to 1, up to 10 to 1. Regular tests are made several times daily with potassium ferricyanide solution for unoxidized ferrous iron in the oxidizing chamber effluent.

At this point it seems appropriate to mention a slightly different interpretation of alum and iron coagulant dosages that has been adopted at the South District Filtration Plant in Chicago. Since the advent of alum solution and ferrous sulfate solution, the conversion of plant dosages back to a dry aluminum or ferrous sulfate basis, is both awkward and unnecessary. Since the effective coagulant is the amount of aluminum or iron present, the practice is to set and report plant dosages as pounds per million gallons of aluminum or iron called for and delivered. This has worked out very well and has been accepted by our technical organization.

Selection of Chemicals for Specific Purposes

Alum is by far the most generally used coagulant. It is effective over a wide pH range in many waters. The ideal pH range is considered by many investigators to be between 6.5 and 7.5. At Chicago we have operated for over 15 years using alum successfully at a pH range of 7.5 to 7.75 (final pH after coagulation). Work done at Chicago's Experimental Filtration Plant indicates that alum will perform quite satisfactory on Lake Michigan water over a pH range of 5.5 to 7.5. Due no doubt to the ion-exchange property of alum, it is usually quite effective in removing colloidal turbidity. At Chicago, we have on several occasions, found it necessary to use mixtures of approximately two-thirds alum and one-third chlorinated copperas, in order to produce a completely clear water. On other occasions we have found it necessary to reverse this ratio.

Ferrous sulfate or chlorinated copperas has the advantage of pro-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ducing 20 to 30 per cent more removal of plankton by settling and proportionally longer filter runs, than alum. When used in conjunction with clays, it has a high affinity for film-oil.

Sodium Aluminate apparently works better on peaty or colored waters and soft, low pH waters containing colloidal clay.

The Ferric Sulfates function in much the same manner as chlorinated copperas. For some plants it is the simpler and cheaper method of producing ferric hydroxide. The use of lime in conjunction with ferrous sulfate instead of chlorine to produce ferric hydroxide, can also be used to adjust the final pH of the water. The absorption of the by-product, carbon dioxide, from the coagulation reaction, by the lime, produces a more compact floc that settles better.

At Chicago it has been found advantageous to add just enough lime to absorb the free carbon dioxide to the alum treated water half-way through the mixing basins after the alum floc has been precipitated. This is usually done when chlorinated copperas is not being used. Coagulants are used in conjunction with the softening process when the softened water contained insufficient magnesium to produce the gelatinous hydroxides necessary for good settling of the softening sludge. Coagulants usually produce a more effective sludge blanket for the up-flow clarifier.

Lime

In softening a water, so much lime is used, that the cost factor becomes most predominant. At least two cities are known to reburn their softening sludge as a source of lime. In the selection of lime for pH adjustment, most plants find it desirable to use hydrated lime. This is fed through a regular type dry feeder, wherein it is made into an approximately 5 per cent solution, which is usually applied to the filtered water. In past years, the larger plants found it desirable on a cost basis, to use quick lime, slaking it and diluting to a 5 per cent slurry. In the analysis of the lime, this will amount to less than 1 per cent, the maximum for insoluble material. However, in large installations, accumulated material known as "grit" can become quite a nuisance. The larger particles are removed by the slaker mechanism. The finer particles remain in the slurry and are carried over into the basins where the grit accumulates and creates a problem of removal. Similar trouble occurs with lime from oil and gas-fired kilns due to small particles of unburned limestone. In the high viscosity slakers (35-40 per cent slurry), these particles of grit and limestone get caught between the blades of the mixer and cause the mixer to stall.

At Chicago we have had some success using hydrated lime, which has become competitive cost-wise. The hydrated lime is made into a 40 per cent slurry in a tank with a turbine-type mixer and is fed directly into the water with a valveless proportioning pump. No check valve type of pump can be used as the lime tends to cake out on the checks and will soon prevent the operation of the valve. Use of this material eliminates the grit removal; the lime can be pumped directly into the slurrying tanks; the equipment is simple and easily repaired.

Advantages and Disadvantages

Alum as a coagulant has the advantage of producing a color-free water. It works over a broad pH range and will preform the dual function of ion-exchange with colloidal and color-body material.

It has the disadvantage of being redissolved by alkalies in the higher pH range. It does not produce the effective floc in settling plankton. The solution form of alum has the advantage of requiring very simple equipment. However, it is a corrosive liquid requiring 316 stainless steel piping and plastic or lead-lined containers. If diluted, the insolubles tend to settle out, plugging pipelines and control valves. The small amount of iron in the alum solution and it's temperature, result in the accumulation of iron bacteria growths in the pipeline.

The advantages of the iron coagulants are that one obtains better plankton removal by settling, with proportionately longer filter runs. Used with clays on oil contaminated waters, better removal is again accomplished. The disadvantage is that it is difficult to obtain a color-free water. The fact that lime can be used with the iron coagulants, even at very high pH without redissolving the iron, is an advantage. Ferrous sulfate solution has all of the advantages of the alum solution. In oxidizing it to the ferric form, the chlorine equipment and the oxidizing chambers are additional necessities. The disadvantages of the ferrous sulfate solution are it's corrosiveness, it's variability in composition and the necessity of testing for heavy metal and other contaminants.

The advantages of the hydrated lime slurry are the simplicity of equipment required and the elimination of the grit-removal problem. The disadvantage is its tendency to cake out in the system. However, this can be controlled.

The advantage of using quick lime and slaking it on the spot is the cost factor. The disadvantages are the extensive equipment used for handling and the grit removal problem.

The coagulation of water is a mining operation. One has no control over the quality of water that comes in at the plant intake. Coagulation jar tests are the most important aid in establishing coagulant doses.

At the South District Filtration Plant, before making a change in coagulant dosage, we consider not only the results of a current jar test, but the turbidity of the raw, settled and finished waters; the quality of the floc in the mixing basins; the degree of settling obtained and the quality of the filtered water.

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FLOCCULATION*

by G. A. ROHLICH and K. L. MURPHY

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■ In water purification the process of sedimentation is practical only when the subsidence velocity of the particles will allow removal within a reasonable period of time. As the particle size approaches the colloidal range the influence of Brownian movement is increased and gravitational effects are minimized. To remove such solids it is usually necessary to enhance their settling properties. With discrete particles and as a supplement with flocculent particles, a chemical coagulant is employed. In order to obtain optimum results with a given chemical dosage, the proper conditions for the agglomeration of these particles must be provided.

Several authors have defined an optimum type of floc. Hudson[12] indicated the floc should be large and dense in order to facilitate rapid settling, and at the same time sufficiently sturdy to resist breakage. Tolman [18] felt the governing criterion was the ratio of floc weight per surface area which again would control the settling characteristics. Among others Calvert [6] and Darby [9] have indicated that the size criterion of floc is not sufficient to judge the success of the process, because large feathery floc would not likely possess suitable settling characteristics.

Theoretical Development

A primary consideration in the mechanism of flocculation is the manner in which contacts or collisions occur. It is through these collisions of the particulate matter that the agglomeration or flocculation process proceeds. In quiescent water or with "ideal flow" in which all particles are subjected to a uniform velocity and no velocity gradient exists, the mechanism causing contact is the difference in the subsidence velocity of the particles.

Consider two particles, the first of diameter, d', and subsiding velocity, v_s'; and the second of, d", and subsiding velocity, v_s''. As stated by Fair and Geyer [10] one collision will occur "if the particles are present in a cylinder of diameter $(d' + d'')$ and height $(v_s' - v_s'')$. The latter equals the vertical distance that can separate the particles and still permit the upper, larger particle to catch up with the lower, smaller particle in a unit of time." If n' particles of diameter d' and n" particles of diameter d" are within the unit volume, the number of contacts per unit volume and time may be expressed mathematically as:

$$N = n'n'' (\pi/4) (d' + d'')^2 (v_s' - v_s'') \quad (1)$$

where: N is the number of contacts per unit volume and time,

d' is the diameter of the first group of particles,

d" is the diameter of the second group of particles,

n' is the number of particles of diameter d',

n" is the number of particles of diameter d",

v_s' is the subsidence velocity of particles of diameter d' and

v_s'' is the subsidence velocity of particles of diameter d".

If the particles are of equal density and are settling according to Stokes' Law then the expression becomes:

$$N = n'n'' (\pi/72)\, g \left[\frac{Sg - 1}{\nu}\right] (d' + d'')^3 (d' - d'') \quad (2)$$

where N, n', n", d', and d" are as previously defined,

g is the acceleration due to gravity,

Sg is the specific gravity of the solid particles, and

ν is the kinematic viscosity of water.

For Formula 2, it is noted that the rate of flocculation is accelerated by:

1. increases in particle concentration,
2. increases in particle size,
3. increases in particle density, and
4. decreases in the kinematic viscosity of the liquid resulting from an increase in temperature.

A considerable increase to the flocculation rate, over that obtained through subsidence velocity differentials, can be achieved through an agitation of the basin and by the introduction of a velocity gradient. A measure of the degree of agitation or disturbance is available in the absolute velocity gradient (G) which exists at a given point. Camp and Stein[7] have indicated that, through a consideration of fluid mechanics, an expression similar to the one relating the number of contacts to the subsidence velocity, can be given. This relates number of contacts for n'n" particles per unit volume and time, to the absolute velocity gradient. This expression is:

$$N = 1/6\, n'n'' G (d' + d'')^3 \quad (3)$$

where N, n', n", d' and d" are as previously defined, and G is the absolute velocity gradient at a given point.

The absolute velocity gradients within a basin, subjected to external agitation, vary with time. Camp and Stein state, however, that if the flow pattern of the basin does not alter with time, and with a steady input of

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work, a mean velocity gradient can be associated with the absolute viscosity, and with the mean value of work input per unit time and volume (Φ_m).

$$\text{Thus } G_m = \sqrt{\phi_m/\mu} \quad (4)$$

Substituting this into equation 3 gives:

$$N = 1/6\, n'n''\, \sqrt{\phi_m/\mu}\, (d' + d'')^3 \quad (5)$$

Inspection of equation (5) shows that particle concentration, size, and liquid viscosity still influence the rate of flocculation. When flocculation results from agitation it is the power input to the basin which influences collision rates. The power input, is analogous to the difference in subsidence velocities or specific gravity of the particles. For a given system the rate of contacts and thus the speed of flocculation is governed by the energy input.

This analysis would indicate that for economy in basin size the velocity gradient, G, should be established at a maximum practical value. This value can be determined through consideration of the definition of viscosity:

$$\tau = \mu G \quad (6)$$

where: τ is the shearing stress, and
μ is the absolute or dynamic viscosity. An increase in power input increases the velocity gradient which causes a directly proportional increase in shearing stress in the fluid, and acts upon the floc. Thus, while a large power input will provide rapid floc formation, it will also hinder the formation of floc of large size.

Conduits and Baffled Basins

The American Water Works Association in the book, "Water Quality and Treatment," [2] state that the first coagulant basins were raw-water conduits following low lift pumps. To obtain the degree of flocculation desired, extremely long conduits were required. This led to the development of the baffled mixing basin once so predominant in the water industry.

Flocculation does occur in normal turbulent flow in a conduit or basin and it is possible from the discharge and head loss to evaluate the work available to cause flocculation. The overall energy input per unit volume and time is given by:

$$\phi_m = \frac{AVWh_f}{AL} \quad (7)$$

where: ϕ_m is the mean energy input per unit volume and time,
A is the cross section area of the basin,
L is the length of the basin,
V is the mean velocity over the cross section,
W is the specific weight of water, and
h_f is the head loss through the basin.

Substituting for $h_f = \frac{fL}{4R} V^2/2g$ for a rectangular basin we have,

$$\phi_m = \frac{f\rho V^3}{8R} \quad (8)$$

This indicates that the power input varies as the cube of the cross sectional velocity. Consequently at low flows and velocities there will be insufficient power input to achieve flocculation, while at high flows power input and velocity gradients may reach such a magnitude that floc formation of appreciable size will be inhibited. In the baffled basin the operator has no control over the energy input and is unable to alter the type of floc produced. Another objection to this type of basin is the high head loss at the 180° bends. This head loss causes excessively high velocity gradients and shearing action in these areas.

Spiral Flow Basins

The spiral flow basin has also been used in the flocculation process. In such basins water enters tangentially at a high velocity inducing a spiral motion within the basis. According to Camp [8] the energy input available for flocculation may be estimated by equations 7 and 8 using the inlet velocity head. For a given detention time it is preferable to use a single basin rather than basins in series. The latter design may produce entrance velocities of a magnitude sufficient to break-up floc that had been formed in the previous basin.

Mechanical Flocculators

A variety of mechanical flocculators is available for treatment of water. The energy required for flocculation generally is imparted through moving blades with either rotary or reciprocal motions. It is the relative motion of water and paddles that governs the drag on the paddles, and consequently the energy input available for flocculation. Maximum efficiency will occur when the relative velocity of the water with respect to the paddles is the same as the shaft speed. Both Camp[8] and Bean [5] state that this can only be accomplished with rotary mechanisms under the following conditions:

1. when the area of a blade is sufficiently small to prevent inducing a flow of the water mass in front of the blade surface, and
2. when provision is made to suppress rolling of the tank contents induced by motion of the blades.

Bean [5] has indicated that the area of the blades in one plane should not exceed 15 to 20 percent of the cross section of the basin if rolling is to be prevented. He further indicated the desirability of stator or mixing blades. Camp [8] added that without stator blades there was no evidence that shaft speed was an indication of relative blade velocity.

For a rotating mechanism the overall energy input per blade per unit volume and time is given by:

$$\phi_m = \frac{F_D v_b}{AL} \quad (9)$$

where: F_D is the drag force on the blade,
v_b is the relative velocity of the blade,
A is the cross-section area of the basin, and
L is the length of the basin.

On substitution with "n" blades this expression becomes:

$$\phi_m = \frac{239\, C_D\, (1 - K)^3\, S_s^3\, \Sigma a \cdot r_b^3}{AL} \quad (10)$$

where: C_D is the drag coefficient of the blade,
S_s is the shaft speed in revolutions per unit time,
KS_s is the speed of water in revolutions per unit time,
r_b is the distance from shaft to blade center, and
a is the area of a single blade.

Camp has indicated that with stators

employed in which $\Sigma a r_b^3$ value was equal to that of the rotors, K values of 0.24 to 0.32 were obtained.

With reciprocating motion the relative velocity of the water with respect to the shaft changes constantly within a cycle thus an evaluation of the mean energy input per unit volume must be evaluated for a complete cycle, and is given by:

$$\phi_m = \frac{\phi_c S_s}{AL} \quad (11)$$

where: ϕ_m is the energy input per unit volume and time,

ϕ_c is the energy input per cycle and unit volume performed by the drag forces, and,

S_s is the shaft speed.

On substitution the following expression is obtained:

$$\phi_m = \frac{12.74\, C_D\, D^4\, S_s^3 \cdot \Sigma a}{AL} \quad (12)$$

This formulation tends to underestimate the energy input, because it neglects the movement of the liquid mass and the inertia effects involved at either end of the stroke. Apparently no data are available to form a basis for estimating this value.

A consideration of the above equations indicates one of the major reasons for superiority of the mechanical flocculators over baffled basins. In the mechanical units the energy input per unit volume and time is dependent upon shaft speed and not upon incoming quantity of flow. Thus, the same rate of flocculation can be obtained regardless of flow. Tolman [18] used the dispersion index to measure the quantity of mixing and found only a five percent change with a flow variation of 100 percent.

Diffused Air Flocculation

Diffused air flocculation has also been used. The work input to the basin may be calculated from either the work of expansion of the air in the bubbles or from the drag forces between air bubbles and liquid. According to Camp [8] the results will be similar. With diffused air the regions of maximum velocity gradient will occur at the bubble water interface. If the bubbles can be distributed uniformly throughout the basin volume a larger portion of the liquid will be exposed to the high velocity gradients than with any other method of flocculation. This makes doubly important the problem of controlling the rate of bubble rise and the accompanying velocity gradient at the bubble surface if maximum floc formation is to be obtained. These values are necessarily controlled by bubble size. Low air rates and small bubble sizes would appear necessary to produce successful flocculation. In practice the use of air flocculation tends to modify the conventional flocculation and sedimentation arrangement. Experience indicates that much of the floc is carried to the surface as a scum much like an air flotation unit. Removal of the floc at the surface reduces the number of contacts possible and decreases the rate of flocculation, thus increasing the required detention time. With air it may be possible to provide skimming equipment with the aeration unit and remove most of the floc from this unit.

Basin Hydraulic Characteristics

In any process which is dependent on time for optimum results, as is the development of an acceptable floc, the evaluation of the hydraulic characteristics of the basin assumes great importance. Nichols [14] stated that in the reproduction of the results of batch studies in flow through units the most common source of failure was through short circuiting. Velz[19] in his review of the subject stressed even further the importance of short circuiting. He stated that the type of flocculation apparatus is important only as it effects the uniformity of floc formation, i.e., all portions of the influent are subjected to the same velocity gradient for the same period. The extent to which short circuiting, dead spaces, or mixing occur within a basin can be determined by hydraulic tracer studies using the dispersion curve technique.

A dose of dye, salt, or other tracer whose concentration can be accurately determined is injected at a known time into the tank influent. Samples of effluent are subsequently collected at known intervals and the concentration of the tracer plotted against time. The curve so obtained, as indicated in Figure 1 is known as the dispersion curve for the basin under test conditions.

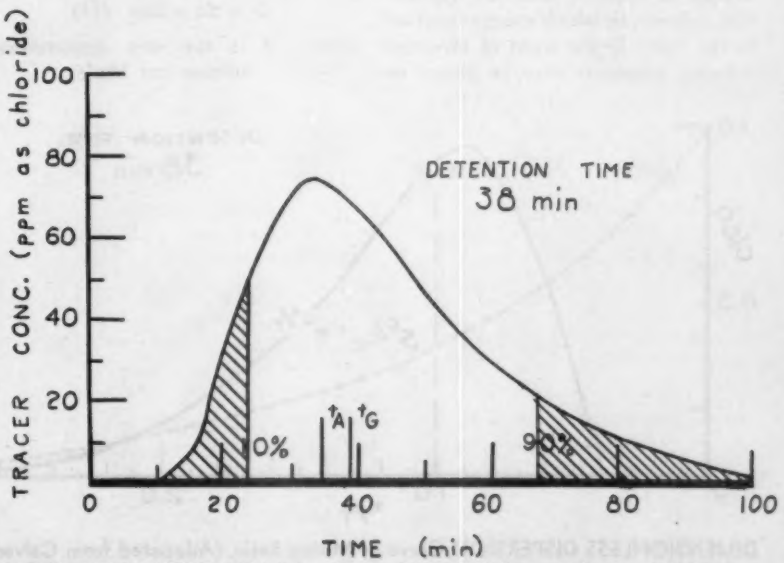
From the analysis of such a curve various dimensionless hydraulic ratios, which are compared to the theoretical detention time, can be defined:

a) Relative time to the initial appearance of the tracer in the effluent (t_i/T),

b) Relative time to the center of gravity of the area under the curve or the arithmetic mean detention time (t_G/T),

c) Relative time to the center of the area or median detention time (t_A/T),

d) Relative time to the peak of the curve or most probable detention time (t_P/T),



DISPERSION CURVE OF Mixing Basin. (Adapted from Calvert—1938).

e) Dispersion index or ratio of time required to pass the first 90 percent of the tracer to that required to pass the first 10 percent (t_{90}/t_{10}).

These dimensionless characteristics may be used to compare results made at different flow rates, with varying amounts of tracer, or with various sized basins.

It is also possible to obtain a dimensionless dispersion curve which incorporates graphically all of the above ratios. Such a curve more than any individual ratio best represents the overall basin behavior. The amount of tracer accounted for in the effluent is represented by the area under the dispersion curve (Fig. 1). This should be close to 100 percent. If this area is divided by the theoretical detention time (T), the result called C_o, is the concentration which would be obtained if the entire dose were uniformly dispersed throughout the volume. If the ordinates of the dispersion curve are divided by C_o and each abscissa by T, a dimensionless curve is obtained which is comparable to all other such dimensionless curves (Figure 2).

Calvert[6], Tolman[18], and Hudson[12], have used this technique for the study of flocculation basin hydraulics. Calvert, working with a well baffled basin obtained a dispersion index of 2.7 to 2.8. This value agreed closely with the 2.5 value proposed by Tolman for a flocculation basin. Tolman further indicated that satisfactory flocculation should result from high hydraulic efficiencies. With the flocculation process, in which energy is added to the basin in the form of imparted velocity, emphasis must be placed on elimination of short circuiting. Hydraulic studies of either prototype or model basins will aid in the assessment of the hydraulic characteristic of the basin and will aid in the selection of suitable baffle arrangements.

Design Parameters

The relationship of power input and velocity gradients and their effect on the rate of flocculation has previously been discussed. As a result of this relationship Camp[8] proposed the use of a dimensionless number (the product of the velocity gradient G and the retention time T). Camp stated that data referring to limiting velocity gradients were meager and he computed the mean gradients for the installations described in the ASCE Manual of Engineering Practice No. 19[1]. With these data he concluded mean velocity gradients range from 20 to 74 sec^{-1} and the GT values vary from 23,000 to 210,000.

Bean[5] in reviewing the factors affecting flocculation agreed that the energy dissipated in eddy currents is the energy avaliable for flocculation. He proposed the use of a displacement factor as a measure of optimum mixing in mechanical basins. He defined this value as:

Displacement factor = D/F

where: F is the total flow, and

D is the displacement volume in the direction of flocculation rotation.

The displacement volume may be calculated by the following:

$$D = \Sigma d = \Sigma aS \quad (14)$$

where: d is the unit displacement volume per blade,

a is the area of one blade, and

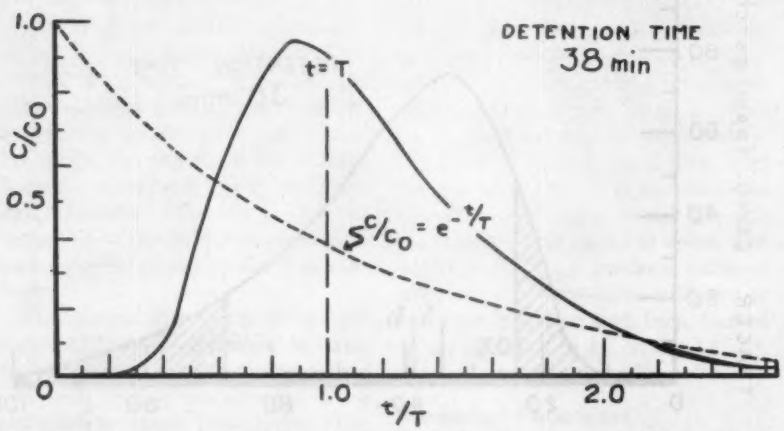
S is the velocity of blade in the direction of flocculation rotation.

Bean suggested that with displacement factors between 30 and 40 good flocculation would result.

Nichols[14] disagreed on the importance of paddle area in the process, proposing that the speed and number of paddles governed the degree of flocculation. He contended that only at high speeds would the wake effect be enlarged appreciably with increased paddle area. Tolman[18] supported this proposal as he felt for a given blade area that a larger number of blades would be more efficient. Both of these authors mention that the clearance of the paddles to the basin wall must be restricted. Tolman suggested a minimum ratio of cross-section swept by paddles to total cross section of 65 percent. This restricted clearance is required if the water most remote from the blades will be influenced without an excessive peripherial velocity and destructive velocity gradient.

Possibly a more conventional design criteria is the actual velocity of flow for baffled basins, bubble velocity in aerated chambers, or velocity of paddles in mechanical basins. These values will vary with the type of coagulant and degree of turbidity present. For baffled basins Baylis[4] indicated values of from 0.8 to 1.3 fps with the higher values optimum for more turbid water. Hudson[12] gives 1.0 fps as an acceptable value while Willcomb[20] gave the range of 0.3 to 1.0 fps. For mechanical mixing the average values of blade velocity cited by the various authors range from 1.0 to 1.5 fps. Hoover [11] and Hyde and Ludwig[13] agree that velocities below 0.5 fps are ineffective in promoting flocculation. Apparently little data are available on the rate of bubble size desirable in diffused air installations.

Langelier, early in the development of mechanical flocculation, postulated the need for a tapering of the rate of agitation through the flocculation process. As has been indicated previously the rate of reaction will vary directly with velocity gradient. Thus, when floc size is small, greater shearing velocities may be tolerated. Late in the process, when the primary purpose is to enlarge the floc, a lesser velocity gradient is required. The reduction in the mean velocity gradient



DIMENSIONLESS DISPERSION Curve of Mixing Basin. (Adapated from Calvert —1938.)

may be achieved either through a reduction of blade velocity or blade area. Since a reduction of blade velocity would reduce the relative velocities in the region of the blades, this should prove more effective in preventing shear of floc particles. Hyde and Ludwig[13] support this concept indicating that with mechanical flocculation, velocities of 2.0 fps can be used initially but prolonged exposure of floc formed from $Al_2(SO_4)_3$ to velocities greater than 1.5 fps results in a smaller floc. If the velocity gradient is increased in the early stages of flocculation then a smaller detention time would be required in a series of compartmented basins to produce the equivalent G-T values for a single basin. In such a series of basins, however, care must be taken to permit a safe transfer of floc between basins.

Detention times for flocculation basins are generally in the range of 40 to 60 minutes. The minimum time will be determined by the attainment of the desired degree of flocculation which in turn is dependent upon the degree of agitation. Batch tests have proved successful in estimating this end point when the degree of short circuiting has been recognized. Increased length of flocculation periods should have no deleterious effect upon the quality and size of the floc if critical velocity gradients are avoided.

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Hypochlorination of Wastes

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EDITOR'S NOTE: This is one of a series of articles published in WATER & SEWAGE WORKS dealing with hypochlorite-chlorine materials and their use in environmental sanitation control. The various subjects reviewed included: the nature, manufacture, storage and handling of hypochlorites; principles fundamental to hypochlorination processes, especially as they relate to municipal water supply, swimming pool and wastes treatment practices; and a discussion of hypochlorite feeding and dosage control equipment that facilitates their safe and effective application.

Writing on the subject are numerous and no single treatise is or can be complete by itself. These articles are not purported to contain all or even a majority of principles, facts or techniques relating to the subject.

With regard to handling and safety suggestions, readers are cautioned that certain circumstances may warrant modified or additional procedure; moreover, cognizance must be taken of any Federal, state, municipal, insurance or other requirements that might apply.

Development

The application of hypochlorites to sanitary wastes preceded their use for disinfection of potable water systems. By 1830, about a half century before the germ theory of disease was established, the use of chloride of lime for deodorizing sanitary wastes had been advocated, and practiced to some extent, on the theory that the control of sewer odors would limit the spread of infection.

The earliest large plant-scale adoption of sewage chlorination (using chlorinated lime) is believed to have taken place in 1854 when the Royal Sewage Commission employed it to deodorize London sewage. By 1859, it had been demonstrated that the application of chlorinated lime to sewage substantially retarded its putrefaction, and the use of this material to minimize or control stream putrefaction was adopted in 1872 at Northampton, England.

The application of chlorinated lime specifically for the disinfection of infectious typhoid wastes was first practiced in England in 1879. In 1894, experiments on hypochlorite disinfection of partially treated sewage were made at Brest and Nice, France, and at Worthing, England. But it was not until about 1907, however, that the practice received much attention of American scientists. In that year, plant-scale studies of hypochlorite disinfection of sewage were undertaken by E. B. Phelps at Red Bank, New Jersey, marking the beginning of effective sanitary wastes disinfection in the U. S. The uses of chlorine and chlorine compounds for purposes other than odor control and disinfection only were recognized and adopted many years later.

There is a paucity of data on the early history of sewage treatment and chlorination in the U.S. during the first few decades of the 20th century. Published data indicate that only 22 of 619 waste treatment facilities (about 35 per cent) operating in 1910 employed chlorination (using commercial hypochlorites then available, largely chlorinated lime). Since that time, as indicated in Table 1, development has been steady, although not nearly as impressive as that pertaining to chlorination of water (See Part II).

Considerable refinement and progress has occurred during the past half century in the quality of commercial hypochlorites and feeding equipment.

Table 1.

Trend in Development of Community Wastes Chlorination in the U.S.*

Year	Treatment Plants: All	Treatment Plants: Using Chlorine	Treatment Plants: % Using Chlorine	Estimated Population Served x 10 ⁶: All Plants	Estimated Population Served x 10 ⁶: Plants Using Chlorine	Estimated Population Served x 10 ⁶: % Benefiting Wastes Chlorination
1910[1]	619	22	3.6	4.46	0.11	2.4
1916[1]	846	55	6.5	6.14	0.28	4.6
1934[2]	3697	655	17.7	22.20	—	—
1940[3]	5580	1127	20.2	40.62	14.34	35.3
1945[4]	5786	1262	21.8	46.86	16.03	34.2
1948[5]	6058	1307	21.6	48.70	18.04	37.0
1957[6]	7518	2216	29.5	76.44	37.84	49.5

*Data are not strictly comparable due to slight variations in statistical reporting and analytical procedures.

In its infancy, disinfection and odor control of sanitary wastes was accomplished by using either chlorinated lime (chloride of lime, bleaching powder, etc.) or sodium hypochlorite. Solution-feed equipment then available often yielded erratic results. Impetus to effective wastes chlorination came with the commercial availability of liquid chlorine (1909) and proprietary chlorinators (1912-1913); the proposal of a practical colorometric method for chlorine residual determination (1909) and its development and subsequent adoption; and, finally, the production (1928) of high-test hypochlorites containing 70% available chlorine.

Data on the relative amounts of liquid chlorine and hypochlorites used for wastes chlorination during the period 1910-1948 are not available. In 1948, of a total of 1307 community wastes treatment plants in the U.S. that had adopted chlorination for disinfection and/or other purposes, only about 8 per cent were using hypochlorites. By 1957, this was further reduced to about 6.4 per cent of all plants chlorinating (See Table 2).

Although hypochlorites are generally more useful and economical than liquid chlorine at smaller plants, a few larger plants also have adopted the material, especially in recent years (See Table 2). The use of hypochlorites in waste treatment, then, is by no means obsolete or diminishing in importance. As shown in Table 3, for the period 1948-1957, there was about a 40 per cent increase in the number of community wastes treatment plants using hypochlorites; those using liquid chlorine increased by about 80 per cent during the same period. However, on the basis of contributing population, this represents an increase of 144 per cent versus 110 per cent for hypochlorites and liquid chlorine, respectively.

Treatment Principles

Normal sanitary and industrial wastes are about 99.9 per cent water. The balance represents a large and complex variety of suspended and dissolved inorganic and organic materials, sometimes in addition to large numbers and varieties of bacteria, protozoa and other organisms. These materials have an effect on wastes chlorination practices similar to that which they have on water chlorination practices. Moreover, their frequently greater numbers, variety and complexity make them even more significant in the establishment of a chlorination regimen suitable for treatment objectives. Because hypochlorites and chlorine-containing compounds are strong oxidants, they are rapidly dissipated in various reactions with many of these materials —an especially important consideration where disinfection or nuisance organism control is the treatment objective.

When high-test hypochlorites (or sodium hypochlorite) are added to liquid wastes, immediate ionization occurs:

$$Ca(OCl)_2 + H_2O \rightleftarrows Ca^{++} + H_2O + OCl^-$$

Hypochlorite ions (OCl^-) establish an equilibrium with hydrogen ions, thus:

$$OCl^- + H^+ \rightleftarrows HOCl$$

The amount of OCl^- and HOCl in solution is a function of pH. Between pH 6.0 and 8.5 there occurs a very sharp change from undissociated HOCl to almost complete dissociation. Thus, chlorine exists predominately as HOCl at low pH levels; above about pH 7.5, OCl^- predominates and exists almost exclusively at pH 9 and above (See Part II, Fig. 1).

The conditions described do not ordinarily persist for any appreciable time.

Because of their oxidative capacity, free available chlorine forms (such as HOCl and OCl^-) begin to react immediately with many constituents normal to most wastes, forming a variety of other chlorine compounds. For example, chlorine in solution reacts with inorganic and organic nitrogen-containing impurities in wastes to form inorganic chloramines (primarily monochloramines and dichloramines at normal pH levels) and organic chloramine complexes. The oxidation potential and disinfecting capacity of these combined available chlorine forms, especially organic chloramines, are considerably less than that for free chlorine forms. Chlorine reacts also with inorganic materials to form chloro-addition or chlorine substitution complexes. Each of these various chlorine-consuming reactions occurs at different rates and exert a chlorine demand which must be satisfied before (or simultaneous with) significant disinfection is accomplished.

Chlorine forms that are able to penetrate cell membranes and cysts or spore walls are believed to react with an enzyme system essential as a catalyst for metabolism. It also is believed that HOCl exhibits substantially greater ability than OCl^- to penetrate cell membranes and destroy essential enzymes, and that dichloramines are more effective than monochloramines, organic chloramine complexes and other possible chlorine forms in producing these effects. These theories currently are used to describe the basis of wastes disinfection.

The literature contains little and conflicting information on the relative efficacy of liquid chlorine and hypochlorite chlorine in wastes disinfection. Regardless of the form in which chlorine is applied, the same chemical equilibria are believed to be established.[7] The relative amounts of HOCl and OCl^- formed depend on the pH of the waste *after* the chlorine is added. The addition of a solution of chlorine gas tends to lower pH (due to hypochlorous and hypochlor-

Table 2.

Distribution of Use of Hypochlorites and Liquid Chlorine For Sanitary Wastes Chlorination in the U.S. (1948 and 1957)[5, 6]

Population Group Served	Number Plants Chlorinating (Min.)						Est. Pop. Served x 10^3					
	Total		Hypochlorites		Liquid Chlorine		Total		Hypochlorites		Liquid Chlorine	
	1948	1957	1948	1957	1948	1957	1948	1957	1948	1957	1948	1957
Under 500	73	146	17	40	41	82	36.5	80.5	5.9	12.0	24.7	55.9
500- 1,000	171	246	30	40	96	166	114.0	182.3	15.1	26.5	70.8	128.9
1,000- 5,000	580	921	49	51	391	674	1,314.2	2,177.4	60.1	86.2	925.0	1,619.3
5,000- 10,000	186	340	4	3	108	244	1,186.3	2,365.2	22.7	17.8	674.2	1,763.7
10,000- 25,000	166	292	3	6	125	218	2,189.8	4,082.9	25.2	72.0	1,654.0	3,041.2
25,000- 50,000	60	127	0	0	51	95	1,862.9	3,991.9	0	0	1,643.5	2,956.1
50,000-100,000	24	54	0	2	18	38	1,317.4	3,366.0	0	100.0	1,175.5	2,546.8
Over 100,000	47	90	0	0	36	67	10,015.6	21,589.1	0	0	7,980.5	15,563.4
Total	1307	2216	103	142	866	1584	18,036.7	37,835.2	128.9	314.5	13,149.1	27,675.3

ic acids formed); whereas, the addition of hypochlorites (due to alkilinity excess) tends to raise pH. Many wastes are well buffered and the effect on pH may be insignificant. Sawyer[8], for example, has observed that the addition of 10 mg/L hypochlorite chlorine had little or no effect on pH of a relatively poorly buffered sanitary waste, but that the addition of an equivalent amount of chlorine water solution depressed the pH of the same waste significantly. In theory then, the addition of equivalent amounts of liquid chlorine (in solution) or hypochlorites should not be expected to yield equivalent results unless the amounts added are so small that the pH of the waste to which they are applied is unaffected.

Oxidation reactions with chlorine are reportedly[8] enhanced by low pH that prevails when liquid chlorine is the disinfectant of choice. (This may account for the greater chlorine demand sometimes observed than when hypochlorites are employed.) Chlorine consumed by these reactions may yet be available for disinfection, but the potency of the compounds formed is of low magnitude. Moreover, the type and amount of chlorine residual formed differs accordingly, depending on the form in which chlorine is applied. For these reasons, Sawyer contends that lesser amounts of hypochlorites than liquid chlorine may be needed to accomplish equivalent results and a lesser chlorine demand may be anticipated.

Additional research is indicated to clarify the relative disinfecting efficacy of liquid chlorine and hypochlorities in wastes treatment. It is abundantly clear that wastes disinfection is a complex subject and that the numerous germacidal chlorine derivatives which can be formed all differ in effectiveness[9]. Also, because of variations and fluctuations in quality of a specific waste, and because of differences in reactions that occur when different forms of chlorine are applied, the chlorine derivatives formed (and consequently, the chlorine residual) vary greatly. The real significance of the extent to which these and other factors affect wastes disinfection and other chlorination processes remains to be fully established.

Other Applications

Chlorine and hypochlorites have been employed quite effectively for a number of years as an aid to coagulation, especially for treating water high in color, iron or organic content. The primary value of chlorine in this connection is its oxidizing power. Many sanitary and many industrial wastes are devoid of oxygen and it frequently is expedient to supply chlorine with chemical precipitation. This is especially applicable when coagulating with iron salts, for in the absence of oxygen ferric iron generally is reduced to the ferrous form having little or no precipitating value. Chlorine and its products are similarly capable of precipitating proteins and fats, a property which makes their application especially suitable in treating industrial wastes (such as those from meat packing houses) that contain large amounts of protein, grease and fat materials.

Thus the utility of chlorine and hypochlorites in wastes treatment is based on oxidative capacity and toxicological characteristics. Any decrease in oxidation potential of chlorine reduces the rate at which reactions with impurities proceed, and also diminishes the bactericidal effect. The amount of chlorine required to carry reactions to an equilibrium at any given time interval is a function of the temperature, pH, concentration and type of oxidizable and chlorine-absorbing materials. The speed and completeness is governed by the law of mass action. Thus, the concentration of chlorine, chloramines and oxidizable substance also affects the mechanism of the reactions and the types of end-products formed. In some cases, oxidation reactions proceed slowly even under optimum conditions of temperature, pH and concentration of reacting substances, and an appreciable time period may be necessary to establish equilibrium. The extent to which biological destruction or attenuation occurs depends on similar factors.

Use with Sanitary Wastes

Chlorine has been employed effectively in one or more steps of practically all conventional wastes treatment processes. A large number of sanitary wastes treatment facilities employ chlorine or hypochlorites continuously for odor and septicity control, BOD reduction, as a coagulant or coagulant aid, or for partial or complete disinfection. Intermittent applications for relieving filter ponding, psychoda problems, sludge bulking, slime and algae control and numerous others, also are popularly employed.

Both liquid chlorine and hypochlorites are effective for these various purposes. Hypochlorites are popularly employed by small plants (See Table 2) and for emergency use by a number of large plants. Moreover, they are especially effective for those

Table 3.

Per Cent Change in Relative Use of Hypochlorites and Liquid Chlorine For Sanitary Wastes Chlorination in the U.S. (Between 1948 and 1957)

Population Group Served	Approximate Per Cent Increase					
	Plants Chlorinating			Est. Pop. Served		
	All	Hypochlorites	Liquid Chlorine	All	Hypochlorites	Liquid Chlorine
Under 500	100.0	135.2	100.0	120.5	103.2	125.3
500- 1,000	43.8	33.3	73.0	59.9	75.5	82.1
1,000- 5,000	58.8	4.8	72.4	65.6	41.8	75.0
5,000- 10,000	82.8	(25.0)	126.0	99.5	27.5	161.5
10,000- 25,000	76.9	100.0	74.3	86.5	185.5	83.7
25,000- 50,000	111.5	—	86.3	114.2	—	79.9
50,000-100,000	125.0	∞	111.0	155.8	∞	116.8
Over 100,000	91.5	—	86.2	115.7	—	95.0
Total	69.6	38.9	82.9	109.7	144.1	110.2

many treatment processes or applications which require only occasional or intermittent chlorination, regardless of volume of wastes involved. Ofttimes their use in such instances eliminates the need of costly equipment and minimizes possible objectionable handling, storing and safety problems associated with some other chlorine forms. They are especially adaptable at institutional, restaurant, camp and similar facilities where relatively small volumes of waste are involved and where ease and simplicity of operation is essential[10, 11]. Within recent years they have been used for treatment of cabin cruiser wastes[12].

Sodium hypochlorite generally is more expensive than high-test calcium hypochlorites and is somewhat less conveniently handled. For these and other reasons, it does not enjoy the popularity of high-test hypochlorites in wastes treatment. However, it does have the advantage of producing considerably less sludge in most applications, and where this is a significant factor, its preference is clearly indicated.

Hypochlorites are applied at upsewer, in-plant or in-stream locations wherever maximum benefit, consistent with the treatment objective, is afforded.

Use with Industrial Wastes

Many industrial wastes are separately treated by the same physical, chemical and/or biological processes commonly employed for treating community wastes. The various uses of chlorine and hypochlorites associated with such processes—odor and septicity control, oxidation, BOD reduction, improved biological filter and activated sludge operation, coagulation, sludge thickening, etc.—are equally applicable to many industrial wastes. Frequently treatment units for handling industry wastes are of much lesser capacity than those required for handling a community's wastes, and hypochlorite chlorine forms may be especially suitable, particularly where treatment is on an intermittent or seasonal basis. They frequently are used to retard septicity, fermentation, slime growth and other undesirable conditions where wastes are temporarily stored pending controlled discharge into a community wastes and receiving system and in transit to the treatment site.

The choice between liquid chlorine and hypochlorites also depends on the methods best adapted to the problems at hand, equipment and installation required for each, concentration of impurities in the waste, variations in the quality and quantity of wastes to be treated, availability and cost of chemicals etc.

The alkaline-chlorination process (batch-type or continuous) is the most commonly employed means of treating cyanide-containing metal processing and refining wastes. Hypochlorites are as effective as liquid chlorine for cyanide oxidation, but the use of high test hypochlorites is sometimes not advantageous because of the large quantities of sludge produced. Hypochlorites are used to some extent, however, particularly where small volumes of wastes are produced. Phenols, too, can be effectively oxidized by hypochlorites, but chlorination must be complete to prevent formation of chlorophenols. Possibly because of the frequently high chlorine demand of phenol-containing wastes, hypochlorite chlorination treatment does not appear to be extensively employed.

Wastes from wool scouring plants are among the strongest and most objectionable of industrial processing wastes. The treatment of such wastes with liquid chlorine was suggested about 1918 and, although a process was patented in the U.S. about 1925, it has never been used commercially. About 1946 a process utilizing calcium hypochlorite for treating wool scouring wastes was developed. Reported by Faber[13], it involves addition of hypochlorite to destroy the emulsified nature of the wastes; the combination of oxidation and coagulation reactions provides good separation of colloidal and suspended solids, and permits easy recovery of wool grease precipated as insoluble soaps. Hypochlorination of wool-scouring wastes is employed at some textile mills.

As noted previously, the efficiency of chlorine as a primary coagulant also permits precipitation of protein and fats typical of meat packing industry wastes. Hypochlorite application (pretreatment) for septicity control, and in-plant application for coagulation is adaptable to treatment of such wastes from smaller packing houses.

Food processing wastes generally contain such a high amount of chlorine-consuming organics that chlorine treatment alone is prohibitively expensive. As an adjunct to other treatment processes for odor control, retardation of septicity, algae etc., hypochlorites are sometimes employed by canning and other food processing industries. Reinke[14] for example, reports that application of sodium hypochlorite at a rate of 20 mg/L is sufficient to destroy odors often associated with land irrigation disposal of milk products wastes.

The problem of reusing beet sugar waste waters in plant operations may be improved by adding hypochlorites to the fresh waters to reduce undesirable fermentation products. The treated waste water should show a residual of 1 to 1.5 mg/L after 10 min. contact.

Recirculation of process waters by many industries, such as white waters in the paper industry, oil refinery

waste waters, condensor and cooling waters and others is possible if slime and other nuisance organsims are controlled. Hypochlorite chlorine forms are especially suitable and are frequently employed for this purpose.

Operational Control

In employing chlorine or hypochlorites in wastes treatment, care must be excersized to select the point (s) of application and dosages in such a manner as to accomplish the objective as efficiently as possible without interference to biological or other chlorine-sensitive processes. Flexibility in operation should be provided.

The considerable variations in the chemical and biological make-up of wastes preclude the establishment of rigid, uniform chlorine residual requirements. The value of maintaining a specified chlorine residual is based principally on demonstration of the effects of such practice on the desired objectives, and conformance to limiting requirements on the quality of the wastes effluent or the receiving water. For disinfection and other purposes, hypochlorination control is practically attained by routine chlorine residual determinations; for some purposes, control is based on a percentage reduction of total chlorine requirement. The chlorine requirement is defined as that amount of chlorine, in mg/L, which must be applied to produce a residual of such strength that, after a definite contact period, the effluent will show a desired coliform density or will meet the requirements of some other treatment objective.

Some applications involve less control and are less susceptible to quality fluctuations and variable chlorine requirements. Or, the treatment regimen may be a preventive, rather than a curative one. In such cases, the application of fixed amounts of hypochlorites in accord with a suitable schedule may suffice, and the effectiveness of treatment may be based on the absence of algae or odor, or on some other simple operation parameter.

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Hypochlorite Feeding Equipment

by EDMUND J. LAUBUSCH,

Hypochlorite Application

Hypochlorites can be applied to potable, wastewater or other sanitary systems in various ways depending on the nature, objective and continuity of treatment and on the form of hypochlorite employed. Hand dosing is the crudest means of application but it may suffice for many specialized purposes, especially those involving only occasional or one-time use. Such instances might include disinfection during well-drilling operations and construction or repair of piping systems or appurtenances, for cleaning reservoirs, for cleaning or increasing well capacity, for algae, psychoda fly or odor control, for disinfection or algae control of wading and other small pools, etc. Hand dosing, at best, is haphazard, involving the human element, uneven hypochlorite distribution, and only approximate control of chemical dosage. Where possible, the use of even the simplest chemical feeder is the preferred means of application. In all cases, thorough mixing of an adequate amount of the hypochlorite with the solution to be treated is essential, and contact time sufficient to insure the treatment objective must be provided.

Fundamentally, there are two basic classes of chemical feeders: (1) dry feeders, in which the chemical is received, measured and dispensed in dry form, e.g., granular or powdered high test calcium hypochlorite; and, solution feeders, in which the chemical is received, measured and dispensed in solution. High test calcium hypochlorites can be applied either through dry feeders or through solu-

tion feeders; sodium hypochlorite can be applied only through solution feeders because dry forms are not commercially available.

There are a variety of proprietary dry and solution chemical feeders that are suitable for, or can be adapted to, applying hypochlorites. In addition, many home made devices can be effectively utilized for some purposes. The utility of all feeders must be evaluated on the basis of dosage control afforded in relation to that desired or needed, ease of operation and maintenance, the degree of supervisory control available or necessary, capacity requirements, pressure conditions against which the hypochlorite is to be applied, dependability, and durability, and numerous other factors. Moreover, feeders must be evaluated on the basis of the characteristics of the hypochlorite to be employed, particularly its stability and corrosive characteristics. In general, the feeder that will effectively do the required job and will require the least amount of maintenance is the one which should be selected.

Dry Feeders

Dry feeders for applying hypochlorites are used less frequently than solution feeders for most purposes. The slightly hygroscopic and corrosive characteristics which high test calcium hyochlorites develop upon exposure to atmospheric moisture limit their adaptability to dry feed. During the past several years, dry chemical feeders have been improved, and many are accurate and reliable. There are now available several dry chemical feeders recommended for hypochlorite service; some are designed to feed as little as 3 ounces of the dry chemical per 24 hours. Dry feeders, however, appear to be more generally acceptable only where hypochlorite requirements are substantial.

Since the advent of tablet forms of high test calcium hypochlorite there has been developed a simplified special kind of "dry" feeder which involves gradual dissolution of the dry chemical and its introduction in solution form into the medium to be treated. The simplest of these consists of actual submersion of a corrosion-resistant basket, perforated polyethylene bag or similar container filled with hypochlorite tablets, usually near the water inlet of a pool, tank, reservoir, or in a pipeline, where maximum mixing can occur.

A more refined type of dissolving device involves the passage of pressure-controlled water through a cylinder containing the hypochlorite tablets, and the introduction, by gravity and the pressure of air contained in the unit, of the resultant hypochlorite solution into the medium to be treated. In one type of feeder, small jets of feedwater, controlled by a rotameter type flowmeter, are injected into the lower portion of a distributor tube containing a bed of hypochlorite tablets. The feedwater slowly dissolves the tablets and provides a continuous discharge of hypochlorite solution. The solution discharge rate presumably can be controlled within certain limits by adjusting the feedwater metering valve. The unit is calibrated to cover feed rates between 0.1 and 2.5 lb/hr of available chlorine against a pressure not exceeding 2-3 psi. Higher rates, up to about 10 lb/hr, can be obtained depending on the temperature and pressure of the feedwater. To obtain the maximum feed rate within the calibrated range requires a feedwater pressure at least 8 psi greater than the pressure at the point of application. The unit reportedly is applicable to continuous or semi-continuous systems involving free discharge, discharge into pump suction, or discharge directly into a pipeline, provided that the pressure at the point of discharge is, or can be reduced to less than 3 psi under flow conditions.

The use of dissolving devices eliminates the necessity of preparing and checking stock, hypochlorite-dosing solutions. It would appear that such equipment is particularly well suited to those situations where exacting dosage requirements are not critical, where the greater expense of more elaborate and versatile feeders can not be justified, and where minimum maintenance and upkeep are important. Such applications might include certain low volume industrial potable, processing wastewater systems, private and semi-private swimming pools, condensor and other cooling water systems etc. Where more exacting control is necessary and chemical requirements are substantial, solution feeders can be more satisfactorily and economically employed.

Solution Feeders

For most purposes, solution feeders are preferable to dry feeders for the reasons already discussed. Moreover, fresh stock hypochlorite solutions, can be easily prepared to conform with chemical requirements, and can be more accurately measured and dispensed than the dry material. Many varieties of feeders are available commercially and cover a wide range of operating conditions and economy. They may be designed for continuous, emergency or specialized chlorinating purposes; they may be either manually controlled, operated automatically at a fixed dosage, or operated to provide hypochlorite solution in proportion to the flow of the medium to be chlorinated; and, they may be operated by electric power, belt drive, rotating shaft, water power, compressed air or by power from a gasoline engine.

For the purposes of this discussion, most commercial solution feeders can be classified either as: (1) positive displacement pump feeders, (2) orifice or venturi feeders, or (3) miscellaneous suction gravity feeders. Only a few representative feeders are mentioned here for illustrative purposes.

Positive Displacement Pump Feeders

Positive displacement pump feeders are perhaps the most accurate and also the most complex type of feeder. Their operation depends on a moveable diaphragm, plunger, gear or rotor which proportions the chemical feed rate, the amount being manually or automatically varied by changing the displacement of the diaphragm or the plunger, or by modifying the speed at which the feeder is operated. Many are available with multiple heads to increase the total pumping capacity or to permit simultaneous, independent measurement and discharge of different chemicals. The pumps may be motivated by electric, water or gasoline power, depending on the requirements of each installation.

Many of them are designed for, or can be readily adapted to, automatic proportional flow control. Two positive displacement, pump type feeders are in general use: diaphragm and plunger. Most utilize poppet valves to control intake and discharge, and most are capable of dis-

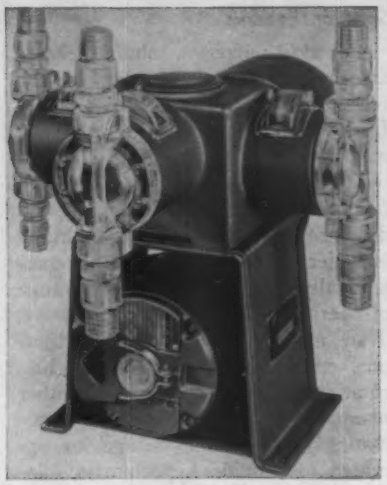


Fig. 1. B-I-F Model 1210 Triplex Chem-O-Feeder Chemical Pump.

charging hypochlorite solution against pressure up to about 100-125 psi. Where discharge is against low or negative heads, the use of an anti-suction device is indicated.

Positive displacement pump feeders appear to be especially applicable where it is necessary to discharge the solution against pressure, where automatic flow proportional feed is indicated, and for continuous treatment systems involving substantial volumes.

Diaphragm Feeders

B-I-F Industries, Providence, R. I., markets a series of electrically-operated diaphragm Chem-O-Feeders, available with simplex, duplex, or triplex pump heads, and suitable for discharge pressures up to 125 psi. Design capacities are rated at 8, 16 and 24 gph, respectively. These solution feeders, illustrated in Fig. 1, are equipped with a three-stop cone drive pulley which permits an overall adjustment range of about 25:1.

The Fischer & Porter Co., Warminster, Pa., electrically-operated diaphragm feeder, available with simplex or duplex pump heads, is designed to deliver up to 65 gal/24 hr, per head, against pressures up to 125 psi. These feeders operate on the principle that a stroke of the pump piston displaces hydraulic fluid which, in turn, creates a pressure on a diaphragm which separates the hypochlorite from the hydraulic fluid. The reciprocating motion of the piston, moved by an eccentric cam, transmits a pulse against the diaphragm which alternately draws hypochlorite solution into the pump and discharges it into the main liquid line. The stroke rate is manually adjustable and controls the feed rate.

Infilco, Inc. Tuscon, Ariz., electrically-operated diaphragm feeder, available with simplex or duplex pump heads (See Fig 2) is designed to deliver up to 2.5, 5 or 10 gal/hr at maximum feed rate, (per head), against discharge heads from —5 to 45 psi. Any feed rate from 1 to 100 per cent of capacity can be obtained,

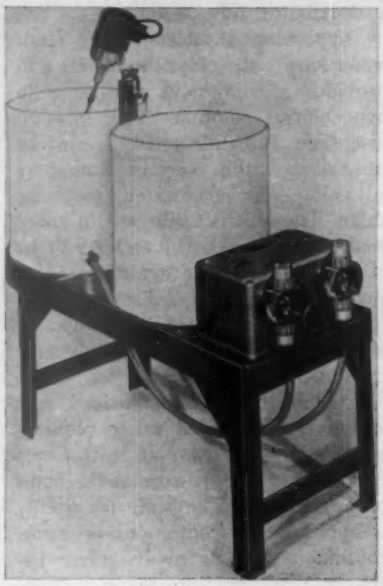


Fig. 2. INFILCO Neusol Duplex Feeder.

reputedly with a consistency of ±2 per cent.

The Precision Chemical Pump Corp., Waltham, Mass., markets two, electrically-operated diaphragm feeders that are especially suitable for hypochlorite applications. Model 801 equipment has an output adjustable between 0 and 20 gal/24hr against pressures up to 60 psi. Model S, heavy-duty feeders, illustrated in Fig 3, are designed to pump solutions at rates from 3 to 60 gal /24 hr, per head, against pressures up to 125 psi; models having up to six independently adjustable multiple heads are also available. In these units a shaded pole electric motor and a reduction gear train reciprocate a diaphragm by means of an eccentric cam. Adjustable over full capacity range, the units reportedly are accurate to within 1 per cent under given pumping conditions.

Wallace & Tiernan, Inc., Newark, N. J., markets a variety of nylon-reinforced rubber diaphragm feeders. The belt-driven A-747-P hypochlorinator operates at capacities of 80, 100 or 250 gal/24hr against pressures up to 100 psi. The stroke length, adjustable over a 10:1 range, can be varied to adjust the feed rate. The "Chlorinet" series, illustrated in Fig. 4, are designed for lighter service and have a capacity of either 1.2 to 6 gal/24hr or 4.8 to 24 gal/24 hr at 100 psi. The pump gear train is driven by a shaded pole induction motor.

In addition to these electrically-powered feeders the company markets a water-powered, "balanced diaphragm" unit (Fig. 5) designed to feed from 0 to 60 gal/24 hr at pressures up to 125 psi in proportion to water flow through a meter. An extension from the meter shaft, which rotates in proportion to flow, pilots the diaphragm pump, and water pressure is used to pump solution in proportion to shaft rotation. Manual dosage adjustments are obtained by varying the length of the pump stroke. Similar feeders are manufactured by H. E. Anderson Co., Muskogee, Ill., and B-I-F Industries, water or air.

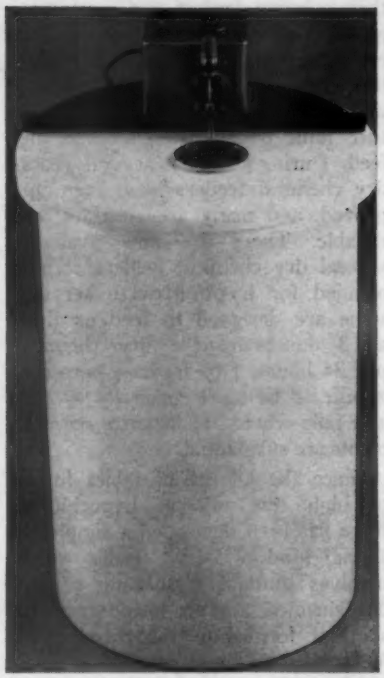


Fig. 3. PRECISION Model S, Heavy Duty Chemical Solution Feed Pump mounted on a polyethylene hypochlorite solution tank.

Fig. 4. WALLACE & TIERNAN Chlorinet Series A-745 Hypochlorinator.

Plunger Feeders

While positive displacement feeders of the diaphragm type appear to be preferred, satisfactory service for hypochlorites also has been obtained using plunger-type solution feeders. For example, the Manzel Co., Buffalo, N. Y., markets a variety of positive displacement solution feeders suitable for handling hypochlorites; primarily these are of the reciprocating plunger type, available in several capacities ranging from 2.6 to 60 gal/hr against pressures up to 5000 psi for some equipment (See Fig. 6). A diaphragm type pump, designed to deliver 1.5 to 15 gal/hr at pressures up to 125 psi, also is available. Drives can be ratchet or direct lever: reduced or direct rotary, belt, chain or motor driven by gas, air or electric motors. A wide variety of muti-feed equipment also is available from this source.

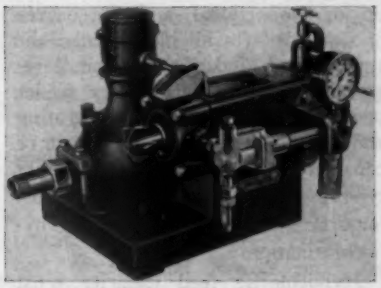


Fig. 5. WALLACE & TIERNAN Water-operated, Proportional Flow Hypochlorinator, Series A-429.

The Milton Roy Co., Philadelphia, Pa., also markets a portable, Model H20 plunger type feeder recommended especially for non-continuous service such as disinfecting new and repaired water mains. This electrically-operated feeder has a maximum metering capacity of 21.5 gph which can be maintained against pressures of 100 psi or more. The company also manufactures a variety of other simplex or duplex "controlled volume", positive displacement feeders covering a variety of operating conditions.

Pressure Differential Feeders

The flow of chemical solution through this type of feeder depends on the development of a pressure differential by means of an orifice, venturi or other constriction. Dosage can be adjusted by either varying the head on a fixed, constant, orifice, by adjusting the hypochlorite solution strength, or by adjusting the orifice size. The most popular of these feeders involve the variable orifice principle of operation. Briefly, a tube from the hypochlorite container is connected to a venturi or orifice in a plastic housing; water from the pressure side of the pump passes also into the plastic housing where it mixes with the hypochlorite, and the mixture is carried to the pump suction where a vacuum exists. This type of feeder is hydraulically operated, simpler than positive displacement pump feeders and, accordingly, less expensive.

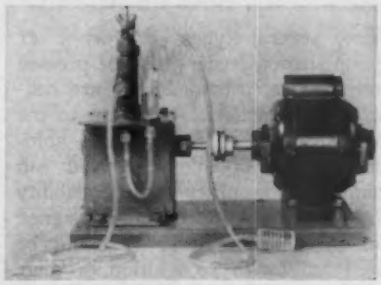


Fig. 6. MANZEL Plunger-type Chemical Pump Feeder.

Fischer & Porter Co., Hatboro, Pa., markets several models of "Super—H Chemical Feeder" ranging in capacity from 2 to 25 gal/24 hr to a maximum of from 50 to 500 gal/24hr against pressures up to 100 psi. One of these feeders is illustrated in Fig. 7. Operation depends on the ejector principle: water enters the chemical feeder, flows through an ejector and creates a partial vacuum which induces the reagent to flow through a metering tube, a rate valve, a differential pressure regulator, and into the main stream flow at the ejector. The flow rate is metered with a rotameter, manually adjusted by a needle valve on front of the unit, and automatically regulated by the differential pressure regulator which maintains a constant pressure across the rate valve. These feeders are equipped with a spring-loaded, backflow check valve.

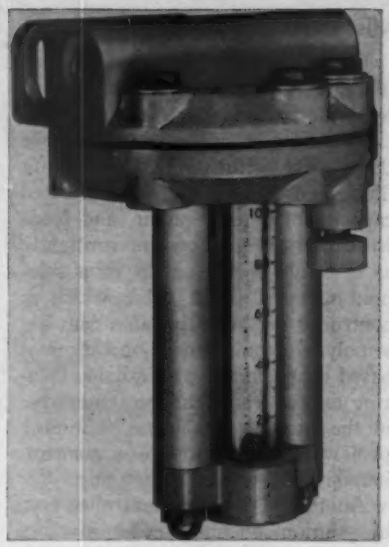


Fig. 7. FISCHER & PORTER Model 70M2021 Super-H Chemical Feeder.

Units operating on the same basic principle, but varying in construction details, are also manufactured by Paddock of Dallas, Tex., having a capacity of about 6½ to 100 gal/24 hr; the Chloromerger Company, Inc., Athens, N. Y., and others.

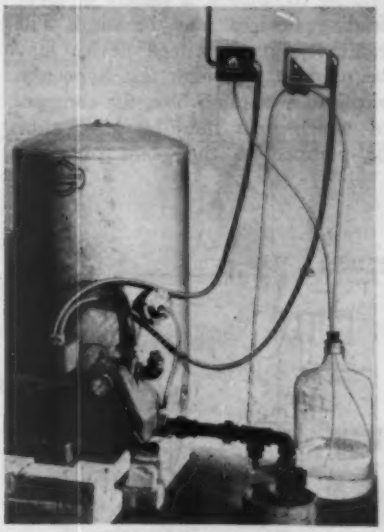


Fig. 8. EVERPURE Everchlor Automatic Interrupted-feed Hypochlorinator.

Miscellaneous Suction Feeders

Everpure, Inc., Chicago, Ill., manufactures an "interrupted feed" type hypochlorinator which utilizes suction, gravity or siphon action to move the hypochlorite solution. The unit illustrated in Fig 8, has a rated capacity of 0 to 5 gal/hr, and feeds hypochlorite solution intermittently as a result of the action of a solenoid-operated pinch valve which is controlled by an adjustable cam assembly. Recommended operation is based on providing an available chlorine excess which can be removed—in the case of potable or swimming pool water treatment—by a companion, optional, dechlorinating unit.

Another simpler air-controlled type of solution, suction, feeder involves connection of the hypochlorite solution tank with the suction side of a water pump and flow control by an air metering device which lets air into the hypochlorite solution container to replace the solution which is withdrawn. The "Chlor-Matic" suction unit (See Fig 9) marketed by Jamco Laboratories, Canoga Park, Calif., operates by this principle.

The above feeders usually are installed to operate synchronously with a water supply or recirculating pump. Recommended use is generally limited to domestic or low flow industrial installations.

Emergency Equipment

For temporary application of hypochlorites, or under emergency operating conditions, a variety of other feeding devices may be used. For example, any dry feed device may be used to feed high test hypochlorite into a solution box, the contents of which may flow by gravity or be pumped to the point of need.

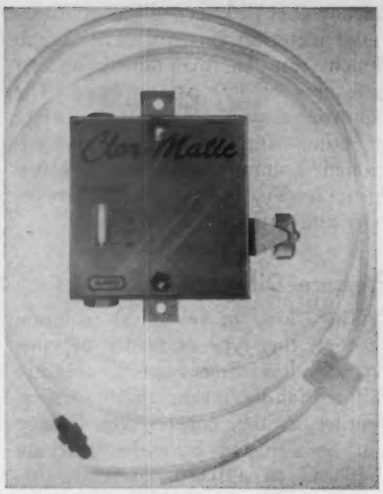


Fig. 9. JAMCO Chlor-Matic Air-controlled Suction feeder.

Also, several types of gravity or pump suction feeders may be pressed into service, provided they are constructed of materials resistant to the corrosiveness of hypochlorite solutions. None of this equipment can compare in accuracy or dependability to liquid feeders specifically designed for this purpose, and it should be used only with recognition of their inherent limitations. Such equipment should be considered makeshift and for only temporary use; under no circumstances should it be provided for standby service such as in the event of gas chlorinator failure.

Feeder Operation

Satisfactory operation of an hypochlorination facility and, consequently, the efficacy of chlorine treatment, can not be assured unless sufficient care is given to the selection, installation, operation and maintenance of the hypochlorite feeder. Principal among the factors to be considered are the type and capacity of equipment, and adherence to minimum maintenance requirements.

Feeder Selection

There is a sufficiently wide variety of hypochlorinators or other chemical feeders currently on the market to cover almost any conceivable situation. The chief considerations involved in selecting a feeder is job requirement; treatment objectives, purpose; scope of treatment, continuous or intermittent; flow to be treated, quantity, quality, and fluctuations thereof; and chemical requirements, amount, kind, and availability thereof. Related to job requirements, adequate consideration also must be given such factors as: available means of actuating feeder, water, air, electric power etc.; point of application, open stream or basin, pump intake or discharge, pressure main, etc. and pressure, positive or negative at the point of discharge; control desired, manual, automatic off-on, or proportional, and, the degree of supervision available. Finally, the amount and kind of maintenance required to insure satisfactory feeder performance, and initial, operating and maintenance costs, also must be considered. Selection of the proper type feeder is the first and most important step towards effective hypochlorination.

Hypochlorite feed capacity must be considered in relation to treatment requirements and strength or potency of the hypochlorite solutions

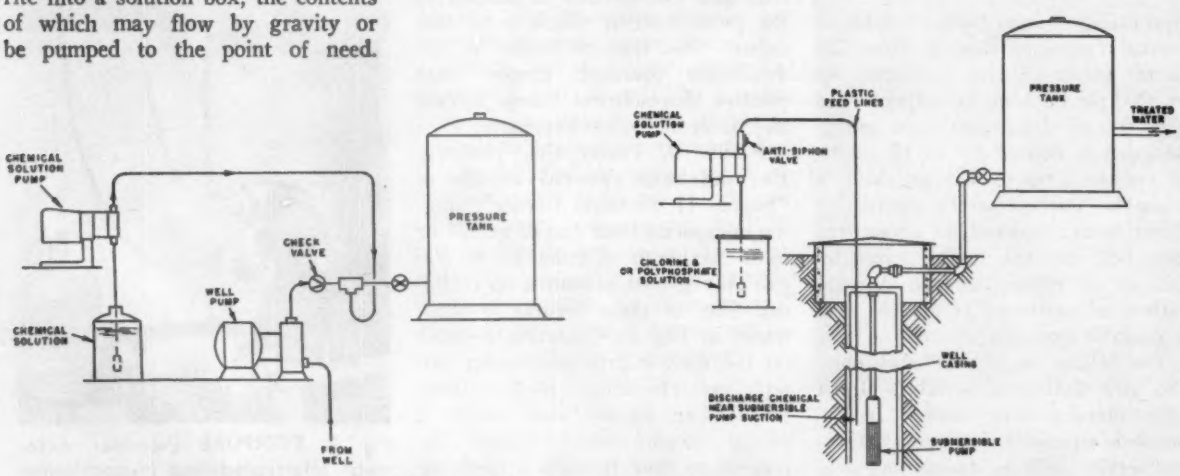
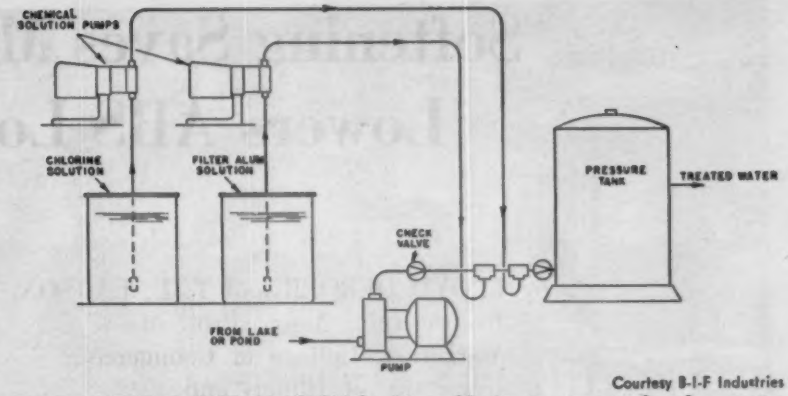


Fig. 10. TYPICAL INSTALLATIONS for Hypochlorite treatment of well water supplies.

applied. In the case of dry feeders, particular precautions must be taken against false weights or volumes resulting from moisture absorption by the hypochlorite, external to or within the feeder itself. In the case of solution feeders, capacity requirements must be based on a solution strength consistent with the design of the feeder. If, for example, industrial strength hypochlorite solutions are not recommended for use with any particular equipment and sufficient chemical can not otherwise be fed under hydraulic conditions prevailing, a feeder of greater capacity may be required; similarly, if chemical requirements are so low as to necessitate use of less than 1 per cent hypochlorite solution at minimum feeder discharge rate, equipment of lesser capacity is preferable. In addition, product stability and degradation must not be overlooked.

Having selected the proper type and capacity of feeder consistent with job requirements and related considerations discussed above, it must be installed and operated in accord with sound engineering principles and professional judgment, and with full recognition of its particular weaknesses or limitations. A number of typical solution-feeder installations are illustrated in Figs. 10 and 11.



Courtesy B-I-F Industries

Fig 11. TYPICAL INSTALLATION for Hypochlorite treatment of surface water supplies.

Feeder Maintenance

No hypochlorinator is so automatic or mechanically refined as to require no maintenance. Even the best of chemical feeders must be regularly cleaned and serviced to insure efficient, continuous operation. Furthermore, unless an alarm system is incorporated to provide warning of interruption of feeding, the hypochlorite supply must be periodically checked and replenished as necessary.

Probably the major source of difficulty associated with most feeders is the clogging of needle control valves, small orifices and venturi throats, ball check valves, inlet and outlet poppet valves and similar constrictions. Clogging appears to be particularly prominent where water contains significant concentration of hardness, iron, mineral and other particulates, and as a result of calcium in suspension in high-test hypochlorite solutions. Often, such deposits are difficult to control or eliminate completely, and accumulations should be removed by brush-cleaning affected parts, using 5 per cent muriatic or acetic acid solutions, as necessary. Daily flushing of all vital feeder components with clear water is a good preventive practice.

Much of the clogging due to calcium deposits can be reduced if proper care is exercised in preparing the hypochlorite solution; i.e., premixing, settling and decanting or siphoning off the clear liquid. There should be a strainer on the feeder solution intake which should be brush-cleaned and flushed daily or as otherwise necessary. In extreme cases, the use of sequestering agents such as sodium hexametaphosphate may be indicated.

Hypochlorinators should be taken apart and inspected at least semi-annually, and worn or damaged parts should be replaced. It is good practice to maintain a supply of replacement parts such as poppet valves, valve seats, diaphragms, O-rings, feeder tubes etc. for ready availability. This is especially important when no stand-by equipment is provided and when continuity of hypochlorite treatment is essential. Strict adherence should be paid to lubrication instructions issued by the manufacturer.

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Softening Saves Money, Lowers ABS Load

by LLOYD DEBOER and T. E. LARSON,
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University of Illinois and
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■ WATER IS RECOGNIZED as one of our most precious resources. As the value of a precious gem is increased by proper shaping and polishing, so the value of water is increased by proper treatment using the best methods available. Hardness reduction is one step in polishing the gem labeled as water.

There are several methods of reducing the hardness of domestic water. These include the use of soap, which is a water softener as well as a detergent, and commercial synthetic detergents, which usually include softening agents as additives. Hardness may also be reduced by the water utility, either with lime (and soda ash) or with ion exchange (such as zeolite) with salt as the regenerant chemical. Home treatment can remove hardness with ion-exchange units. Such units may be either home owned and regenerated, or rented and serviced by commercial water conditioning organizations.

This study reports on the contribution that a reduction in hardness can make to improved quality for the user as measured by the monetary savings in the domestic use of detergents and additives. What saving may be expected from using waters having lower hardness levels, *exclusive* of convenience, greater cleanliness, maintenance of facilities, and life of laundry goods? Although necessarily omitted from this study, these exclusions are well recognized as important economic considerations relative to the hardness parameter of water quality. The study also shows the *decrease* in use of synthetics which relates to the concentration in sewage treatment effluents.

Relative Costs For Hardness Reduction

To provide a basis for comparing the costs of softening water by use of soap or synthetic detergents, three equations have been developed by which the costs of softening by municipal or domestic treatment can be estimated on a relative basis. The results permit a comparison in the per capita cost per 100 ppm per 1,000 gallons.

The results of this study show the gross purchase savings in additives (i.e., the cost of softening water by these additives) per capita per 100 ppm hardness reduction as $1.15 per year, which is approximately 11.7 cents per 100 ppm per 1,000 gallons water used for cleansing, bathing, etc. (Fig. 1)

Municipal Treatment

Municipal treatment, of course, purifies all water and corrects for iron removal, taste and odor control,

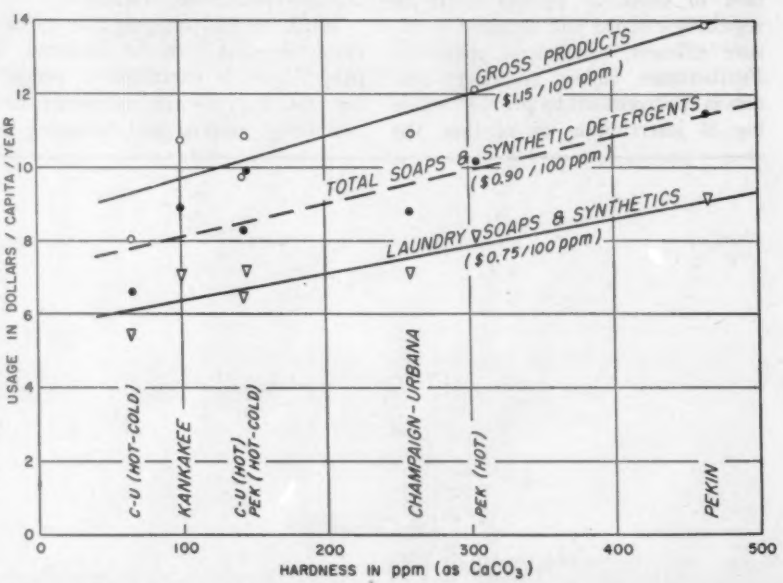
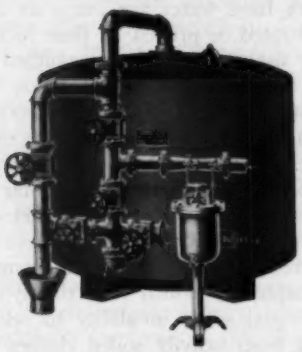


FIG. 1. Effect of Water Hardness on Usage of Detergents and Additives

Roberts-equipped Gravity Type Filter plant, reinforced concrete construction, 8 million gallons per day capacity.

Wheeler Monolithic False Filter Bottom, cast in place.



Style "L" Vertical Pressure Filter—for industrial applications, as well as swimming pool recirculation systems.

experience and cooperative service . . .

Over 60 years devoted exclusively to the manufacture and installation of water purification equipment. Throughout the United States, Latin America and Canada are hundreds of Roberts-equipped installations serving municipalities, and many industrial operations depend on Roberts Filters for process water. Over 5 billion gallons of water every day flow through Roberts equipment.

Roberts supplies the full range of equipment for water filtration and softening plants, including pressure filters, vertical and horizontal types, wood and steel tank gravity filters, equipment for reinforced concrete gravity filters, filtration plant specialties, Zeolite water softeners, swimming pool recirculating systems.

In addition, an extensive engineering organization is maintained, which is at your command on all water purification problems. This service complements the Consulting Engineer in charge of improvements. We invite the opportunity to cooperate with all engineers and architects interested in the rectification of water, either for municipal or industrial applications.

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DARBY, PENNA.

and corrosion prevention. The cost allocated to softening may vary from 5 cents to 15 or 20 cents per 1,000 gallons, depending on the degree of hardness removal, the size of the plant, and the extent of treatment for other improvements.

The average domestic consumption of water may usually vary from 40 to 60 gpcd, of which it is generally assumed that about 27 gpcd, or 9,850 gallons per capita per year, are used for purposes (such as laundry, bathing, cleaning, and cooking) requiring softened water.

The effective cost of municipal hardness reduction may be calculated by the following equation:

$$\frac{100 \times A \times E}{B \times C} = \text{cents per 100 ppm per 1,000 gallons}$$

where A = cost of water charges allocated to hardness reduction, in cents per 1,000 gallons.

B = average daily per capita use of water only for purposes requiring soft water, in gallons

C = reduction of hardness in ppm

E = average daily per capita water use in gallons

Therefore, at an assumed 5-cent per 1,000 gallon cost increment for hardness reduction from 250 to 75 ppm and a per capita water use of 50 gpcd of which 27 gallons are for softened water purposes, the increment for hardness reduction would be 5.3 cents per 100 ppm per 1,000 gallons.

If the hardness reduction were 400 ppm at a 20-cent per 1,000 gallon allocation for municipal treatment, the effective cost would be 9.3 cents per 100 ppm per 1,000 gallons.

Home Softening

The usual commercial salt requirement for regeneration is about 0.4 or 0.5 lb per 1,000 grains, and for domestic home-owned softeners 1 to 2 lb per 1,000 grains is usually used in order to obtain minimum frequency of regeneration. The *minimum* salt requirement for the regeneration of water softeners is 0.3 lb per 1,000 grains of hardness. This figure is based on proper application and backwashing with certain exchange materials of high regeneration efficiency at this level.

The per capita cost of salt may be calculated from the following equation:

$$5.85 \times A \times S = \text{cents per 100 ppm hardness reduction per 1,000 gallons}$$

where A = cost of salt in dollars per 100 lb.

S = salt usage in lb per 1,000 grains of hardness reduction

On the basis that the regeneration step takes place at the time that the exchange capacity of the softener becomes exhausted, a minimum of 1.75 lb of salt is required for each 100 ppm hardness per 1,000 gallons of water. At a domestic price of $2.00 per hundred lb, the minimum cost of salt may be calculated to be 3.5 cents per 100 ppm hardness reduction per 1,000 gallons. With a usual average home use of 1 lb salt per 1,000 grains, the cost would be 11.7 cents per 100 ppm hardness reduction per 1,000 gallons.

Because the salt requirements do not represent the total cost of home softening, an estimate for amortization of the water softener should be included. The amortization cost may be calculated from this equation:

$$\frac{100{,}000 \times (A/E + .025\ A)}{3.65 \times B \times C \times D}$$

= cents per 100 ppm per 1,000 gallons

where A = cost of softener, in dollars

B = daily per capita use of softend water, in gallons

C = hardness of water in ppm

D = number of household members

E = life of softener, in years

and the lost interest on the investment is 5 percent per year.

At a softener cost of $250 and at a 10-year amortization period, this cost would be about $31.25 per year (depreciation plus 5 percent on investment). For a four-member family using 27 gpcd of softened water, the cost would be 80 cents per 1,000 gallons. If the water had 250 or 500 ppm hardness, the cost would be 32 or 16 cents, respectively, per 100 ppm hardness reduction per 1,000 gallons. For a two-member family these figures would be doubled. The true cost of home softening is the sum of the salt requirement and the amortization cost.

Serviced Softening

The charges for serviced softening include the cost of salt, the rental or amortization of the softener, and convenience of service.

The cost of serviced softening per 100 ppm hardness reduction per 1,000 gallons may be simply calculated from the following equation:

$$\frac{100{,}000 \times A}{3.65 \times B \times C \times D}$$

= cents per 100 ppm per 1,000 gallons

where A = annual service charge, in dollars

B = daily per capita use of softened water, in gallons

C = hardness of water in ppm

D = number of household members

Thus for a family of four using 27 gpcd with 250 ppm hardness water and a service charge of $60 per year, the cost is 61 cents per 100 ppm hardness reduction per 1,000 gallons, and for a family of two with a 200 ppm hardness water and a service charge of $42 per year, the comparable cost is 107 cents.

The annual per capita cost per 100 ppm hardness reduction can be determined by multiplying the calculated cents per 100 ppm hardness reduction per 1,000 gallons by 9.85.

The utility treatment and the home treatment for hardness reduction readily supplement each other[1]. Whatever method of hardness reduction is used, the housewife still depends on detergents to do the cleaning job. The quantity of detergent required, whether soap or synthetic, will depend in part on the hardness of the water.

The advantage of the synthetics with hard water are many as demonstrated or proven by their increasing usage. However, as pointed out by Aultman[2] their composition suggests that water hardness affects the quantity required for adequate cleaning. The heavy duty or all purpose products which comprise by far the greatest segment of the market contain 30 to 50 percent sequestering ingredients. These may be complex phosphates* which help the syndets to equal soaps in ability to remove dirt from heavily soiled clothes and for general cleaning purposes.

These sequestering ingredients are also softening agents because they react with calcium and magnesium, the hardness components of water, and therefore in hard water are de-

*Usually sodium tripolyphosphate (STP) and tetrasodium pyrophosphate (TSPP) and more recently tetrapotassium pyrophosphate (TKPP) in liquid heavy duties.

creased in effective concentration for their cleaning purpose. Thus, more product is required in hard water than in soft water.

Because many families substitute or supplement synthetics and soaps with softening agents, scouring compounds, and bleaches, it is reasonable to expect that the consumption of these additives would also be related to water hardness. Therefore, in this study data on these products were also obtained.

Method of Procedure

Three cities were chosen for the study; Kankakee (KKK), Champaign-Urbana (C-U), and Pekin (PEK). At Kankakee, the water utility clarifies and softens water from the Kankakee River to a hardness of 100 ppm as well as chlorinating and treating the water for taste and odor removal.

At Champaign-Urbana, well water is treated for iron removal and chlorinated. The weighted average hardness as determined from the pumpage and analysis of the water from wells used during the study was 258 ppm.

At Pekin, no treatment is provided other than chlorination. The average hardness was determined from 48 samples collected twice per month from five selected locations in the distribution system during the study and found to be 465 ppm.

In each of these three communities a panel of households was selected by probability sampling procedures. Number selected in Kankakee was 169; in Champaign-Urbana, 274; and in Pekin 230. More households were selected than desired as it was anticipated that there would be dropouts during the study. The number of households selected in Champaign-Urbana and Pekin were greater than at Kankakee, in order that a sufficient number who softened some or all of the water could be classed as separate panels. In addition to dropouts, all households that did laundry for persons other than household members were eliminated in the correlation studies as were those that used commercial laundries or laundermats.

Each household reported monthly, on a diary form, their purchases of the products included in this study. The time period covered by their reports was seven months, July 1959 to February 1960. The diary form was mailed to the household each month as a reminder to record each purchase. Purchase data were usually reported by brand of product, size, and cost. At the start and at the end of the time period covered by the study, a complete inventory of all soap and synthetic detergent products and other additives on hand was taken by trained interviewers. By use of these purchase data and inventory data, computations provided the amount and value of each class of product used by each household while a member of the panel.

The individual products used by the households were grouped into twelve product classifications for analysis: light duty soap, heavy duty soap, bar soap, light duty synthetic detergent, heavy duty synthetic detergent, bar synthetic detergent, general household cleanser, scouring compound, dishwasher compound, shampoo, package softener, and bleach. Information obtained from manufacturers on the nature of their products and the type of cleaning job each was designed to perform served as the basis for this classification so that each group would be reasonably homogeneous on these two points.

Shampoo purchase records and questionnaire data on use of beauty parlors were considered separately from the other parameters because it was noted that lower shampoo usage was associated with families that patronized beauty parlors.

Home Softener Performance

It became evident early in the process of evaluating results that the assumptions on the hardness of home softener effluents were not valid. Preliminary analysis of the data were shocking, because it appeared that those living in Pekin who softened their water used as much or more soap and synthetic detergent products than did the people living in Champaign-Urbana who were using unsoftened water. Therefore, in both Champaign-Urbana and Pekin, the hardness of the hot and cold water to the laundry was determined by random sampling at 35 homes.

Four at Pekin and two at Champaign who reported both hot and cold water softened were found to have softening only for hot water. After transfer of these panel members to the proper classifications, the remaining members under the hot and cold classification were visited twice for additional samples for hardness determinations. The interviewers were asked by some to come back at another time, because the softeners needed regeneration. However, a sample of water was taken at that time in order that a statistical average could be based on random sampling of the hardness of the water being used by these families. Table 1 shows the results of this random sampling.

Obviously the human element involved with softener regeneration depreciated the full value of these units as related to this study. The new, completely automatic home units offer a solution to this problem.

For the softened hot water classification, the average hardness was found to be 205 ppm at Pekin and 67 ppm at Champaign-Urbana. In the absence of definitive data it was arbitrarily assumed that 60 percent hot water and 40 percent cold water were blended, or used alternately, for washing and cleaning purposes at homes where only hot water was softened. Therefore in this hot classification, for Pekin average hardness was selected as 306 ppm and for Champaign-Urbana, 143 ppm.

The average hardness of the samples from the hot and cold softened

Table I

Summary of All Samples Collected from Softener Effluents at Champaign-Urbana and at Pekin

	Champaign-Urbana		Pekin	
	Rentals	Owned	Rentals	Owned
Median Hardness	12 ppm	12 ppm	40 ppm	100 ppm
Number of Samples				
Total samples	14	34	13	37
Less than 11 ppm	6	16	3	9
More than 200 ppm	2	4	3	16*

*Nine of these 16 samples had a hardness greater than 400 ppm.

water classification was found to be 145 ppm at Pekin and 67 ppm at Champaign-Urbana.

Results

Figure 1 shows the dollar costs and the savings by hardness reduction for average per capita use of gross products—detergents and soaps, with general household cleansers, scouring compounds, softening additives, and bleaches.

Also in Figure 1, the per capita usage of laundry detergent products alone, and the usage of all soap and synthetic detergent products including bar products and general household cleansers are indicated. It should be recognized that within each of the hardness classifications there was about a ten-fold variation in per capita usage of products. The vertical range of the statistical standard error is therefore quite high.

The slope of the line of best fit as determined by the least squares method using the 398 families indicated the savings for gross products by hardness reduction to be $1.15 per capita per 100 ppm hardness removed. The 95 percent confidence limit for the seven average values was $0.68. Therefore, if Champaign-Urbana water is treated for a proposed 75 ppm hardness, the per capita savings would be $2.10 per year (if no home softener is presently used) or $7.35 per year for the average family size of 3.5 members. At Pekin the per capita savings would be $4.20 per year if the hardness was reduced to 100 ppm. Neither of these figures includes the many additional monetary savings, besides the convenience, that would accrue.

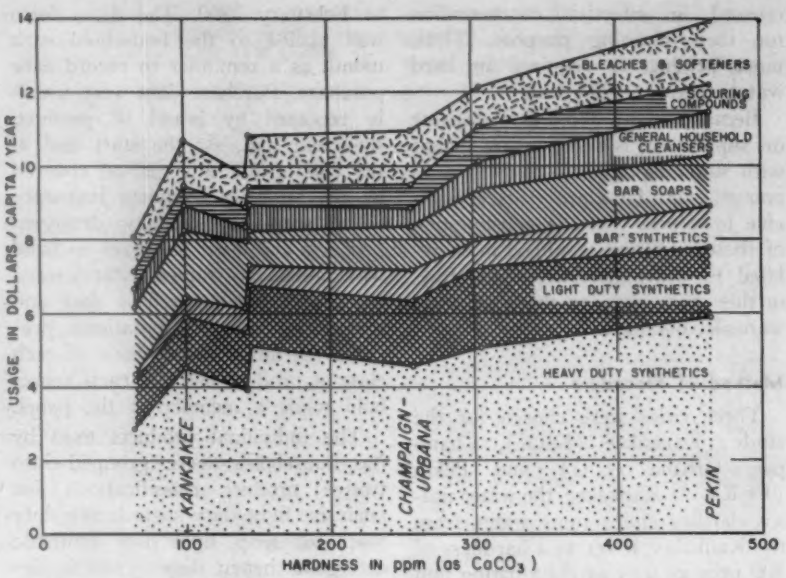

Fig. 2. Effect of Water Hardness on Cost-Usage of Various Products

Figure 2 and Table 2 show the breakdown of the use of gross products by product classifications. Synthetics occupy the bulk of the usage with the heavy duty products predominating. The classification of heavy duty detergents does not include the general utility products such as "Mr. Clean," "Handy Andy," and "Lestoil" which are also synthetic products and often used for laundry purposes.

It will be noted in Table 2 that the use of light and heavy duty soaps is negligible in all three Pekin categories and in the Champaign-Urbana unsoftened water category. Of the total soap and synthetic detergent products, exclusive of general household cleansers, the percentage of soap usage increases with decreasing hardness (Table 3).

Analysis of the characteristics of those panel members in Champaign-

Table 2

Average Dollar Usage of Products Per Capita Per Year

	City and Type of Home Softening						
	C-U Hot-Cold	KKK None	C-U Hot*	PEK Hot-Cold	C-U None	PEK Hot*	PEK None
Number of Families and Average Family Size							
	17	105	28	13	106	34	95
	3.6	3.7	4.1	3.6	3.5	3.2	3.7
Average Cost in Dollars per Capita per Year							
Heavy duty synthetics	2.84	4.54	3.94	5.11	4.59	5.07	5.85
Light duty synthetics	1.36	1.38	1.56	1.66	1.74	2.20	1.91
Bar synthetics	.16	.50	.61	.51	.82	.73	1.12
Dishwashing compounds	.05	.02	.29	.00	.05	.02	.00
Heavy duty soap	.46	.19	.24	.00	.06	.01	.05
Light duty soap	.35	.28	.08	.00	.08	.07	.03
Bar soap	.96	1.36	1.25	.98	.98	1.26	1.27
Household cleansers	.45	.69	.36	.71	.50	.83	1.22
Scouring compounds	.49	.58	.53	.50	.68	.90	.74
Softening compounds**	.65	.63	.54	.93	.91	.73	.91
Bleaches	.25	.55	.36	.46	.50	.29	.82
Total	8.02	10.72	9.76	10.86	10.91	12.11	13.93
Average Cost in Cents per Ounce							
Synthetics	1.89	1.82	1.71	1.84	1.84	1.86	1.88
Soaps	2.29	2.41	2.26	2.72	2.63	2.48	2.60

*Blend of 60 percent "softened" hot water with 40 percent unsoftened cold water.
**Includes ammonia, borax, phosphates, soda.

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Anthracite Institute Building — **WILKES-BARRE, PENNA.**

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— an Improved Filter Medium

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Palmer Filter Equipment Company, 822 E. 8th St., Erie, Penna.

Anthrafilt and Its Application

Anthrafilt is made from a **selected** Pennsylvania anthracite which has been cleaned so as to have a minimum ash. This cleaned anthracite is then screened and classified hydraulically to yield sizes suitable for filter purposes.

Anthrafilt is used as a mechanical aggregate in place of sand and gravel in all kinds of filters, i.e.

Rapid gravity filters	Slow filters
Swimming pool filters	Pressure filters
Hot process softening filters	Oil removal filters
Cold process softening filters	Alkali filters
Mechanical sewage filters	Acid filters
Revolving screen filters	Sewage sludge-beds
Portable filters	Household filters

The entire filter bed may be made up of Anthrafilt of various sizes or only the top layer may be of Anthrafilt over the usual bed of gravel.

Advantages of Anthrafilt

High Filtration Rate: Rates up to 200 mgad are obtainable with Anthrafilt without sacrifice of effluent quality. The accepted average rate with sand is 125 mgad.

Long Filter Runs: The larger, irregular Anthrafilt grains allow less clogging with algae or other fibrous substances. The angular grain surfaces provide greater entrapping areas for the removal of turbidity and bacteria. The differences in shape and specific gravity of the grains, by decreasing classification after back washing, allow the whole depth of the filter bed to be active in the filter operation.

Low Wash Water Costs: The long filter runs and consequent less frequent washing and the low degree of packing after back washing combine to cut the usual wash water requirements at least in half.

No Cementing with Lime, Manganese or Iron: Lime will coat on Anthrafilt but this coating readily flakes off without any cementing action if filters are properly operated. Manganese and iron salts precipitated on Anthrafilt by the lime treatment are easily removed by back washing.

High Degree of Expansion: 50% expansion is obtained with half the back wash velocity required for sand.

Coarse Sizes Can Be Used: The irregular shape and natural filtration characteristics permit the use of much larger sizes with equal results.

Gravel Beds Stay Flat: No ridging or mounding and less cracking and pulling away from side walls during operation.

Low First Cost: Lighter weight per unit volume balances the cost differential between Anthrafilt and sand and saves on freight and handling charges.

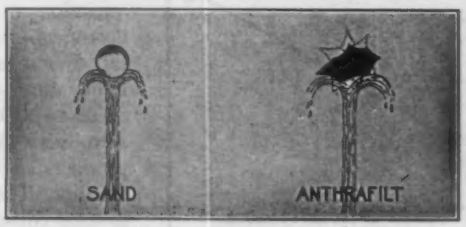
Filtration Characteristics

Anthrafilt granules are irregular shaped and of varying densities. Weights run about 53 pounds per cubic foot as against 100 pounds for sand. The irregular shapes provide greater porosity resulting in more rapid filtration with no loss in character of effluent and with considerably less loss of head.

The variable densities of Anthrafilt particles cause less classification after back washing and the lighter, irregular shapes allow easier expansion and more effective cleaning.

The greater bulk of Anthrafilt requires less tonnage per filter bed. Attrition losses amount to less than 0.25% per year.

Anthrafilt successfully removes lime, iron and manganese salts and will not form a permanent coating under proper conditions of treatment and filter operation. Lime flakes off easily without cementing and the iron and manganese salts are readily removed by back washing. Oil is easily removed from boiler water after coagulation with ferric sulphate, ferrous sulphate or alum. Anthrafilt can also be used for the filtration of acetic and sulphuric acids and caustic soda solutions. Being insoluble in alkaline waters. Anthrafilt produces silica-free water in hot process water softening.



Upward impulses of water produces greater agitation of angular grains, hence Anthrafilt beds are cleaned more effectively.

Anthrafilt No. 1 is usually made in sizes ranging from effective size of .60 m.m. to .80 m.m. The uniformity coefficient is less than 1.75 in all sizes. We can make smaller sizes or larger sizes, but for special cases only. The remaining sizes of Anthrafilt are as follows:

No. 2. Anthrafilt—3/32"x3/16"
No. 3. Anthrafilt—3/16"x5/16"
No. 4. Anthrafilt—5/16"x9/16"
No. 5. Anthrafilt—9/16"x13/16"
No. 6. Anthrafilt—13/16"x1-5/8"
No. 7. Anthrafilt—1-5/8"x2-7/16"
The above sizes have 20% tolerance.

ANTHRAFILT ECONOMY

When Used in Existing Filtration Plants

Increased capacity with same plant
Decreased volume of wash water
Lower maintenance cost through elimination of ridging, mounding and air binding.

When Used in Existing Filtration Plants

Lower plant investment
Lower cost per cubic yard
Lower wash water costs
Lower maintenance costs

Urbana and Pekin who practice home softening indicated decidedly that they are families who are more likely to have higher incomes. They also have the corollary characteristics of older age groups, college or post college education, professional or managerial occupation, and ownership of dishwashing machines and automatic washers.

Figure 3 shows the decrease in usage of synthetic detergents with decreasing water hardness. The line of best fit calculated by the method of least squares shows the average per capita use of synthetics increases 50 ounces per capita per year for every 100 ppm increase in water hardness. From the standpoint of detergent pollution, hardness reduction from 300 ppm to 100 ppm will thereby reduce the domestic ABS in the sewage plant and the plant effluent by 25 percent. If reduced to 10 ppm, the use of synthetics would be reduced by 35 percent.

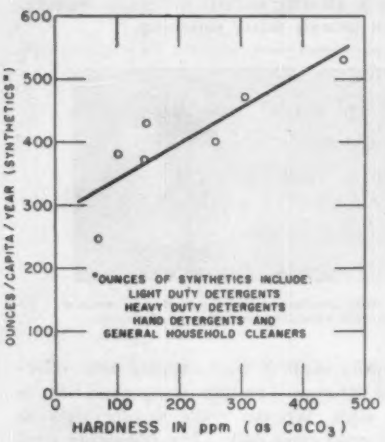


Fig. 3. Effect of Water Hardness on Use of Synthetics

Only eight of the 398 families, representing more than 1,500 individuals, were found to be identical as to six selected socio-economic characteristics. These eight families use an automatic washer; the head of the household has a craftsman occupation; he is 30-39 years of age; he graduated from high school; they have 2 children; and they have a family income of $6,600-10,399. None of them practiced home softening and two came from Kankakee with three from each of the other communities.

As shown in Figure 4, the total consumption of all products in dollars varied substantially among these eight families, from a low of $7.02 per capita per year to a high of $15.80. There was also substantial variation in many of the product classifications which go into this total. For example, heavy duty plus light duty synthetics range from $4.28 to $10.85, and certain families were very large users of particular products as compared to the other families. There was no consistency in total consumption among the families nor among the products consumed by any two of these families. Therefore, it is evident that no one family, even within a given set of socio-economic characteristics, can be considered as "typical" with regard to the use of detergents.

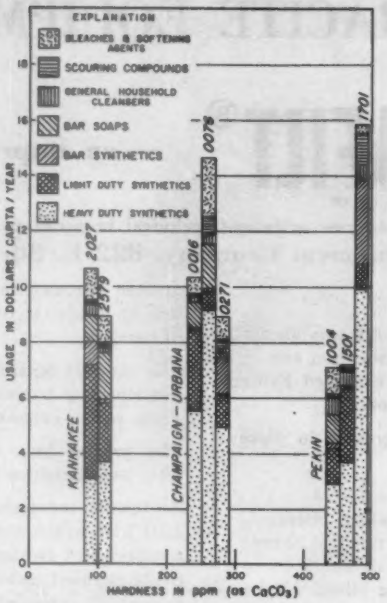


Fig. 4. Cost-Usage for Eight Families Having "Identical" Socio-Economic Characteristics.

Table 3

Per Cent Soap Usage of Domestic Detergent Consumption

City and Type Home Softening	Hardness (ppm)	Soap Usage % of Total
Champaign-Urbana (hot and cold)	67	24.6
Kankakee (none)	100	17.6
Champaign-Urbana (hot)	143	15.6
Pekin (hot and cold)	145	8.6
Champaign-Urbana (none)	258	10.8
Pekin (hot)	306	10.8
Pekin (none)	465	9.9

Use-Cost Changes Since 1931

Comparison with the Hudson-Buswell study[3] in 1931 shows that present day consumption of detergents and soaps is about 120 ounces per capita per year less than 30 years ago when synthetics were not available (Fig. 5). Possible reasons for this lower usage are the greater efficiency per unit weight of synthetics versus soaps and lowered cleaning requirements due to improved working conditions and the general replacement of coal as the general base for heat and energy.

However, the prices of soap and detergent products have gone up, so present day costs for these cleaning products range from approximately $3.75 to $4.50 per capita per year more than in 1931. Yet the need and use of smaller amounts of synthetic detergents are primarily responsible for per capita savings approaching $3.80 in Kankakee,

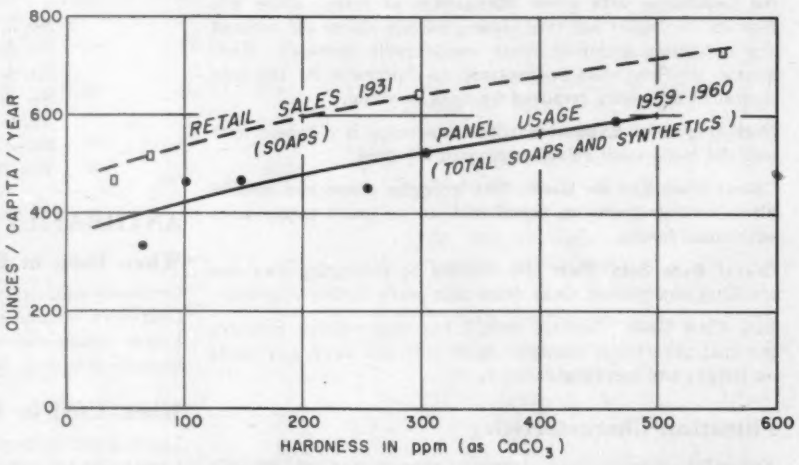


Fig. 5. Effect of Water Hardness on Weight Usage of Soaps and Synthetics in 1931 and 1959-1960

$4.75 in Champaign-Urbana, and $6.10 in Pekin per year as compared to the cost of *using soaps only* at the rate used in 1931 but at 1960 prices (Fig. 6).

It is therefore evident that synthetics have particularly benefited users of harder water, although substancial savings are still to be realized with hardness reduction.

Conclusions

1. The savings for soaps, synthetics, general household cleansers, scouring compounds, bleaches, and other additives used were found to be $1.15 per capita per year per 100 ppm hardness reduction. Municipal treatment for hardness reduction can normally be expected to result in detergent and additives savings of more than the cost increment for treatment when the domestic per capita consumption is near 40 to 60 gallons per day.

2. The maximum polish for this gem of water can be provided by home softeners to reduce the hardness to less than 10 ppm.

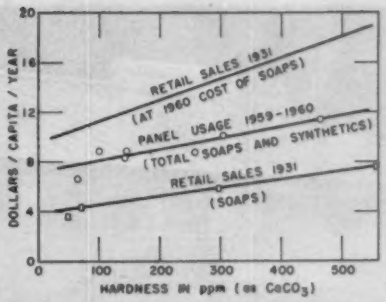


Fig. 6. Effect of Water Hardness on Dollar Usage of Soaps and Synthetics in 1931 and 1959-1960

3. The use of synthetic detergents decreases by 50 ounces per capita per year for each 100 ppm reduction in hardness.

4. The general replacement of soap with synthetic detergents has introduced a decrease in pounds per capita consumption since 1931. This alone has largely resulted in a savings at Kankaee, Champaign-Urbana, and Pekin approaching $3.80, $4.75, and $6.10 per capita per year, respectively, if soaps were the only detergent products now available.

5. The major cost of home softening is in amortization and/or service charge which decreases for use of harder waters and for increasing family use of softened water. This is similar to the amortization cost which may be attributed to automobile driving mileage per year; since the depreciation per year is a fixed charge, the cost of amortization per mile decreases for greater driving miles per year.

References:

1. Larson, T. E. Municipal and Home Water Sotening. *Jour. AWWA*, 45:557 (June 1953).
2. Aultman, William W. Synthetic Detergents as a Factor in Water Softening Economics. *Jour. AWWA*, 50:1353 (Oct. 1958).
3. Hudson, H. W. & Buswell, A. M. Soap Consumption and Water Quality, *Jour. AWWA*, 24:859 (June 1932).

This small building houses a 5-mgd water filtration plant employing . . .

Versatile Diatomite Filters

by N. J. KENDALL, Chief Engr.
San Jose Water Co., Saratoga, Calif.

EDITOR'S NOTE: Four fully automatic diatomaceous earth filters are installed in the building shown above. The limited space requirements, variable flow rates plus varying raw water quality, the automatic controls and the advantage of using intake pumps also as filter pumps, have made this diatomite filter plant an economical method for supplying municipal water needs.

■ A FULLY AUTOMATIC diatomaceous earth filtering system has been placed in service at Saratoga, Calif. The system rated at 5 mgd, is designed to treat water from a mountain stream for domestic use. Fresh water supplies previously obtained from deep wells are now used as auxiliary resources.

The increasing demand for water forced the San Jose Water Co., to develop surface water resources existing as streams in the steep mountain canyons. The lack of room prevented economic construction of large water treatment facilities and thus the diatomaceous earth system without any pretreatment was tried. The original plant was constructed at New Almaden in August, 1957, as a test plant. Although only rated at 185 gpm (1.6 gpm/sq. ft. of filtering area), this plant produced as high as 260 gpm during peak hot weather consumption periods. In winter, after storms, the raw water received at this plant often had a turbidity exceeding 100 mg/l.

The experience at New Almaden led to the construction of a similar plant at Saratoga. The Saratoga plant is 20 times larger and employs four automatic filters which can operate in any combination to produce a rated plant output of 3500 gpm.

Objectives of Saratoga Plant

The filter plant, located on a mountain stream, serves as the main or base load water source for the San Jose Water Co. The plant takes all the water available from the stream. In the summer the stream flow is minimal, therefore the company relies on deep wells as the source of water.

The cost of pumping water from deep wells, located in the valley, is comparable to the mountain filter plant costs, only when the turbidity of the mountain stream reaches 50 mg/l. Well pumping is expensive; therefore, is used as little as possible.

Stream Water Quality

The mountain stream supplying water to the Saratoga filtering plant is not subject to contamination by human sewage. The turbidity of the water is induced by normal run off and increased at times by road construction, road maintenance, and similar activities upstream. During the dry season the turbidity of the raw water ranges between 5 and 10 mg/l. The rainy season causes the

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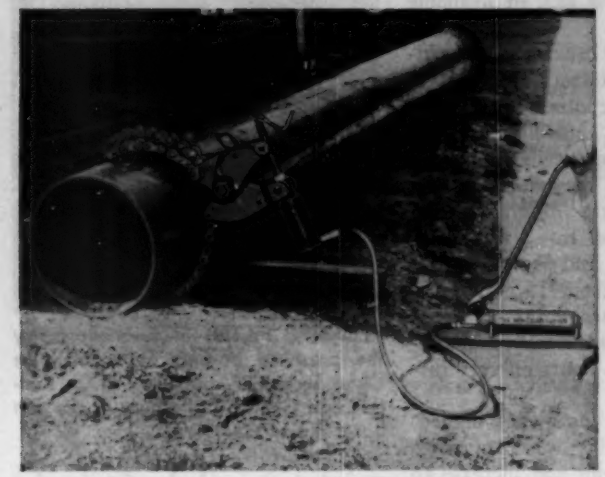
CAUGHT IN THE ACT!



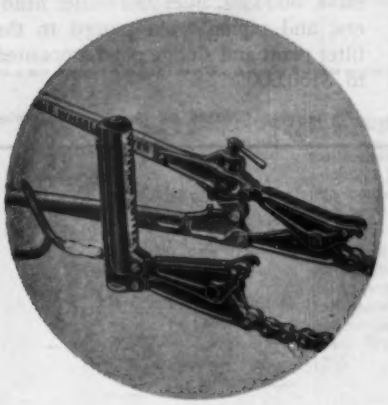
A WHEELER HYDRAULIC PIPE CUTTER "SQUEEZES AND POPS" A LENGTH OF LARGE DIAMETER WATER MAIN. **The Wheeler Heavy-Duty Hydraulic and the SUPER Hydraulic can handle a wide range of pipe sizes and materials quickly and easily. All you do is wrap the chain around the pipe, engage it in the cutter's upper jaws, adjust out the chain slack and operate the hydraulic pump.**

Cutting capacities of the Wheeler Heavy-Duty Hydraulic

- Cast Iron Pressure Pipe—4" thru 10" ASA class 26
- Cast Iron Pressure Pipe—4" thru 12" ASA class 22
- Std. or XH Soil Pipe—All Sizes
- Terra Cotta or Tile Pipe—thru 36"
- Asbestos Cement Pressure Pipe

The Wheeler SUPER Hydraulic will cut cast iron pressure pipe 10" through 20" diameter and tile through 42" diameter

The Wheeler Heavy-Duty and SUPER Hydraulic cutters will snap large diameter tile easily and cleanly.



FOR LIGHTER PIPE CUTTING JOBS

You can choose between the famous Wheeler Manual Cutter and the new Wheeler Jr. Hydraulic.

The Manual Cutter (top left) will cut

- **2" thru 6" Std. or XH Soil Pipe**
- **2" thru 8" Corrosion Resistant Pipe**
- **4" thru 15" Tile**
- **4" thru 8" Asbestos Cement Pipe**

Optional extra chain needed for larger sizes

The Jr. Hydraulic Cutter (bottom left) will cut all pipe in the Manual Cutter's range plus std. or XH soil pipe through 8" and C. I. water main 2" thru 3"—Cutter has convenient separate pump. Optional extra chain for sizes over 8".

Note: Maximum pipe size requirements for each model will determine total price and must be specified when ordering.

THE WHEELER MANUFACTURING CORPORATION

P. O. Box 688 **ASHTABULA, OHIO**

W.&S.W.—REFERENCE NUMBER—1961

CONTROL PANEL regulates operation of the diatomaceous earth filters at the Saratoga plant. N. J. Kendall, Chief Engr., San Jose Water Co., makes adjustments.

turbidity to increase to 50 mg/l or more.

In years of normal rainfall, the stream has maintained a flow of 5 mgd both winter and summer. Recently, the rainfall has been low and the stream is producing only about 1.5 mgd. These seasonal stream flow variations require the filter plant to operate accordingly.

Pumps, located at the stream, lift water from the intake well and serve also as filter pumps. The pumps have variable-speed drives and regulate output according to available input during periods of low stream flow.

Filter Plant

The entire plant can be operated on a wide variation of flow rates using various combinations of the four available filter units. The operator merely sets the flow rate desired and the plant automatically adjusts. The flow rate is usually set slightly higher than the minimum actual flow in the stream. This causes the level in the wet well to drop periodically requiring the plant to go on recirculation until the wet well level is restored. In this manner, the unattended plant is able to catch every available drop of water coming down the stream. The recirculation prevents any loss of filter cake or plant disruption due to the lack of available input.

Precoating and backwashing of filter systems is automatic. Diatomaceous earth is fed continuously during filtering runs at a controlled rate and the filter is automatically taken out of service when the predetermined maximum pressure differential, or minimum filtration rate, is reached. The backwashing and precoating operations require about 15 minutes.

The filter runs average 72 hours on water with low turbidities and decreases down to 6 hours on very turbid water.

The operating costs vary accordingly. Low turbidity waters average about $6.00 per mg and increase to around $30.00 per mg when the turbidity is more than 50 mg/l. At turbidities over 200 mg/l the cost of water is somewhere around $150 per mg, but well pumping can be relied upon during any short periods of adverse stream conditions, such as these.

Filter backwash is retained in a sludge pit where the solids are permitted to settle and the clear water returned to the stream. Settled sludge is removed about once a year; settled water is drawn from the pit once a day. The volume of backwash amounts to less than 1 gal per 1000 gal treated; therefore, a sludge pit measuring 50 x 15 x 5 ft has served very well.

Safety controls prevent any filter going on line until it is properly precoated. Likewise, the plant fails safe on any power interruptions.

The only manual operations required are the refilling of diatomaceous earth slurry tanks and assuring a chlorine supply. This can usually be accomplished by one visit each day by company personnel.

RELATIVE FILTER SIZE is shown by the presence of Sam Felix (left), De Laval Turbine Pacific Co.; N. J. Kendall and Charles B. Parbury of the San Jose Water Co.

Both the New Almaden and the Saratoga filter installations are of the package type which are also used in many industrial applications. Treated water effluents from these units normally have zero turbidity and realize at least 85 per cent reduction of bacteria before chlorination. The filtration system plus post chlorination have provided the citizens of Saratoga, Calif., a versatile method of economically supplying their need for water.

The filter installation cost of the Saratoga plant, including wet well, slabs, building, inlet and outlet headers, and piping from pumps to the filter plant and sludge pond amounted to $150,000.

—Photos were furnished by the DeLaval Turbine Pacific Co.

Smith-Blair Products-Engineered for Permanence and Efficiency for Every Pipe O. D. Requirement

Full-Circle Clamp Couplings

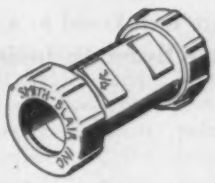
Smith-Blair's recessed armor insures an even distribution of pressure. Ribs between the small grids of the gasket concentrate band pressure to make a more effective seal per pound of bolt torque. Made in widths and sizes to repair holes, splits, full breaks, etc. in all sizes and kinds of pipe. Write for Smith-Blair Folder No. 1263.

Redi-Clamps/Sta-Grid Gaskets

A leak clamp designed to efficiently and quickly repair pin holes, cracks, splits, etc. in steel pipe. Sta-Grid gaskets, having gridded neoprene vulcanized to 26-gauge stainless steel, give inventory savings. Only 3-inch Redi-Clamps and Sta-Grid Gaskets are required to make any repair. Standard sizes through 8-inch Std. Write for Folder No. 1270.

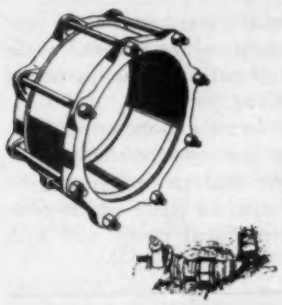
Taper-Seal Service Saddles

Taper-seal gaskets provide built-in pressure compensation. The 180° wrap-around body design insures pipe support at four points around the pipe. A truly ENGINEERED Service Saddle that works with the pressure and the pipe itself. Single-, double-, and triple-strap saddles available for pipe sizes through 20-inch nominal in ductile iron or bronze. Write for Smith-Blair Folder No. 1228.



Compression Couplings

Wedge-type gaskets and malleable iron end nuts and sleeves are features of the Smith-Blair Compression Coupling which has many applications for connecting plain end steel pipe through 2-inch standard. Long and standard sleeve lengths are available; gaskets can be furnished in plain or protected neoprene. Write for Folder No. 1265.

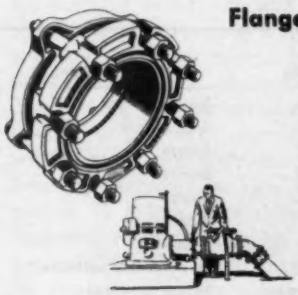


Cast Couplings

Smith-Blair Cast Couplings provide long life connections for cast-iron or asbestos-cement pipe. In straight and transition (up to ¾" variation in O.D.) sizes through 24-inch nominal, and in reducing sizes (up to 1½-inch variation in O.D.) through 12-inch nominal. Write for Folder No. 1216.

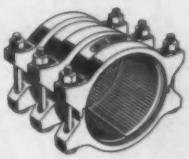
Steel Couplings

Smith-Blair steel couplings include straight short and long-sleeve designs, transition sizes through 14-inch nominal, and special fabricated reducing couplings that provide a reducing coupling for virtually any combination of pipe sizes. Write for Folder No. 1230.



Flanged Coupling Adapters

Smith-Blair Flanged Coupling Adapters provide a direct flexible connection from flanged fittings to plain end pipe. They save space, make flanged fittings easily removed and replaced and reduce installation time. Available for all sizes and classes of plain end cast iron, asbestos-cement, or steel pipe. Write for Folder No. 1255.



Fast-Action Clamp Coupling

For the repair of splits, full breaks, or connecting pipe with ends separated by as much as 1-inch. An all-cast repair unit that is more economical and easier to install than cast repair sleeves and split couplings. Sizes through 12-inch nominal. Write for Folder No. 1254.

Other Smith-Blair products are available for virtually every water and sewerage pipe line O.D. requirement. Smith-Blair products are stocked close to you for prompt delivery. Branch offices and warehouses: Greensburg, Pa.; Tacoma, Wash.; South Gate, Calif.; Texarkana, Tex.

Smith-Blair, Inc., 535 Railroad Ave., South San Francisco, Calif.

SMITH BLAIR

Pump Materials — *Part I*

by IGOR J. KARASSIK, Consulting Eng. and Manager of Planning, Harrison Div., Worthington Corp., Harrison, N. J.

EDITOR'S NOTE: This first of two parts on materials discusses the factors that must be considered in selecting the materials of which centrifugal pumps and their parts and fittings are to be made. These considerations are then keyed to a standard listing of parts already proposed to the Hydraulic Institute.

■ CENTRIFUGAL PUMPS can be manufactured of almost all the known common metals or metal alloys, as well as of porcelain, glass, and even synthetics. But it is beyond the scope of this article to present a listing of all the liquids which may be encountered in centrifugal pump applications with a corresponding tabulation of the materials commonly recommended for each of these liquids, as such a listing can be found readily in the standards published by the Hydraulic Institute, as well as in the catalogs and bulletins of pump manufacturers. A complete detailed listing of recommended materials can be obtained from manufacturers who specialize in centrifugal pumping equipment for various chemical services. It is in this latter application that one can find the greatest variety of special problems. Therefore, the current discussion is limited to certain general considerations in the selection of materials used for the various parts of a centrifugal pump.

Of course, the conditions of service and the nature of the liquid to be handled determine the most satisfactory materials for the construction of centrifugal pumps. Some of the factors which enter into the selection of the materials are:

1. Corrosion resistance.
2. Electrochemical action.
3. Abrasiveness of any suspended solids.
4. Pumping temperature.
5. Head per stage (as it affects both the impeller peripheral velocity and the liquid velocities in the waterways).
6. Operating pressure.
7. Suitability of the material to the structural features of the particular pump involved.
8. Load factor and expected duration of the pumping installation.

The first analysis concerns itself with the separate parts which comprise a centrifugal pump and with

Table I

MATERIALS USED[a] IN CENTRIFUGAL PUMPS

Part No.[b]	Name	Standard-Fitted Pump	All-Iron Pump	All-Bronze Pump
1	Casing	Cast iron	Cast Iron	Bronze
35	Suction Head	Cast iron	Cast iron	Bronze
4	Impeller	Bronze	Cast iron	Bronze
12	Impeller ring	Bronze	Cast iron or steel	Bronze
3	Casing ring	Bronze	Cast iron	Bronze
	Diffuser	Cast iron or bronze	Cast iron	Bronze
5	Stage Piece	Cast iron or bronze	Cast iron	Bronze
2	Shaft (if sleeve used)	Steel	Steel	Steel, bronze or monel
2-A	Shaft (if no sleeve used)	Stainless steel or steel	Stainless steel or steel	Bronze or monel
10	Shaft sleeve	Bronze	Steel or stainless steel	Bronze
15	Gland	Bronze	Cast iron	Bronze

[a] Materials for bearing housings, bearings and other parts are not generally affected by the liquid handled.

[b] Parts in this table and in Figs. 1 through 4 are numbered according to a proposed standard listing suggested to the Hydraulic Institute by C. J. Tullo, Chief Engineer, Worthington Corp. This proposed standard gives stationary parts odd numbers and rotating parts even numbers.

the materials most commonly used for each of these parts.

Pump Casings

Centrifugal pump casings usually are made of cast iron. However, cast iron at normal temperatures has definite strength limitations and a cast-iron casing of a given design will only be suitable for a definite pressure limit. If higher pressures are encountered (either through operation at higher than design speeds or through the existence of high suction pressures), the design must be modified to obtain greater strength or a metal which can be stressed to a higher value (such as cast steel) must be substituted for the cast iron.

Occasionally, pumping systems are subjected to water hammer or shock pressures far in excess of the normal operating pressures and a stronger metal than cast iron is necessary.

Although theoretically it might be possible in some cases to use a cast-iron casing under high pressure, the required thickness of metal would not be satisfactory from the point of view of foundry practice. Sometimes the substitution of thinner cast steel sections for heavy cast-iron castings may compensate the higher material cost, almost to the point where use of cast steel is the more economical solution. Whereas each centrifugal pump design has its own pressure and temperature limitations, there is an upper limit where practical and economic reasons dictate the use of the cast steel regardless of pump design. Thus, cast-iron casings are seldom used for pressures greater than 1,000 psi and temperatures greater than 350 F.

Insofar as temperatures are concerned, it must be considered that the repeated heating-up and cooling-off of a pump handling a hot liquid will aggravate any minute imperfections in either iron or steel castings. There is no absolute certainty that a casing, which was originally tight, will remain tight after the unit has been in service for an extended period. If a leak does develop in a cast-steel casing, it can be corrected by welding. The same process may be impractical in the case of a cast-iron casing.

It must also be considered that piping for use under high temperature and high pressure conditions is generally made of steel. As it would not be desirable to have a pump casing weaker than the piping itself, steel casings are generally preferred in such pumping systems. Even in the matter of pipe connections, the selection of the casing material plays a part; it is not recommended to use cast iron when raised face flanges are used on the connecting piping.

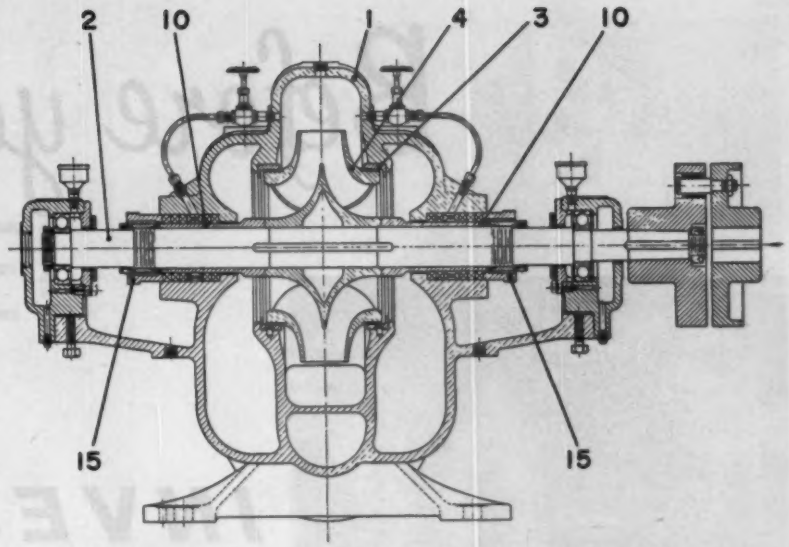


FIG. 1. SECTION of a double-suction, single-stage pump with shaft sleeves.

Cast iron loses in tensile strength and becomes quite brittle at low temperatures. For this reason, casings of pumps handling liquids at very low temperature (such as brine) are generally made of alloyed cast iron or cast steel.

Bronze is frequently used for pump casings when the liquid pumped is mildly corrosive (for instance, sea or harbor water). Stainless-steel casings are used when the pumped liquid is corrosive or excessively abrasive. Porcelain or glass casings are sometimes used for very special applications.

Impellers

Bronze impellers are generally preferred for handling average waters because bronze is easier to cast when complicated core sections are involved, it is easier to machine, smoother surfaces can be obtained, and, finally, because bronze does not rust. However, it is not desirable to use bronze impellers with cast-iron

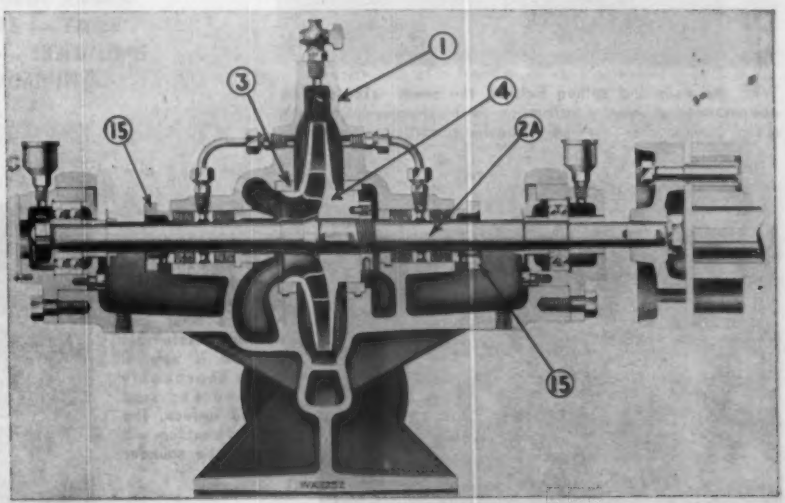


FIG. 2. SECTION of a single-suction, single-stage pump without shaft sleeves.

Before you BUILD,

INVESTIGATE

Shown here is the inside of a storm sewer after cleaning and with steel mesh in place ready for applying Gunite.

ONLY GUNITE OFFERS YOU:

GREATER STRENGTH. Due to the low water ratio of Gunite the structural strength is almost double that of hand poured cement.

GREATER WEATHER AND FROST RESISTANCE. Because of its high density, penetration of water and other destructive agents are held to a minimum.

RESISTANCE TO HEAT AND CHEMICAL ATTACK. Due again to high density Gunite is more resistant to alkali and acid attack than ordinary cement.

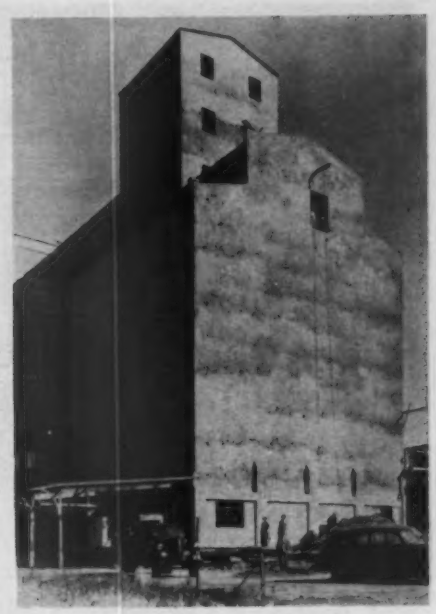
LOW COST. Where the basic structure is sound, renovating with Gunite can be considerably less costly with no sacrifice in strength or permanence.

With the walls and ceiling finished the sewer takes on the appearance of new construction with structural strength much greater than that of ordinary construction methods.

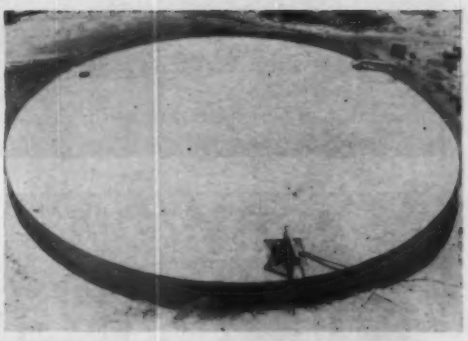
These two pictures give an excellent view of Gunite being applied pneumatically to a river lock structure. Note that Gunite is applied over a thoroughly cleaned and sand blasted surface. The finished structure will actually be sounder than new.

REPAIR or RENOVATE!

THE METHOD OF "GUNITE" CONSTRUCTION



Buildings too, such as this grain elevator can be efficiently renovated with Gunite.



The finished product is now ready for many more years of use and at a fraction of the replacement cost.

This huge concrete tank has undergone a thorough cleaning, with reinforcing mesh already in place, it is ready for applying "Gunite."

"GUNITE" IS THE MODERN METHOD (SAND AND CEMENT APPLIED PNEUMATICALLY) OF REPAIRING, CONSTRUCTING AND LINING: RESERVOIRS — DAMS — FILTER PLANTS — TANKS — SEWAGE DISPOSAL PLANTS — STADIUMS — BRIDGES — SEA WALLS — SWIMMING POOLS — ALL TYPES BUILDING.

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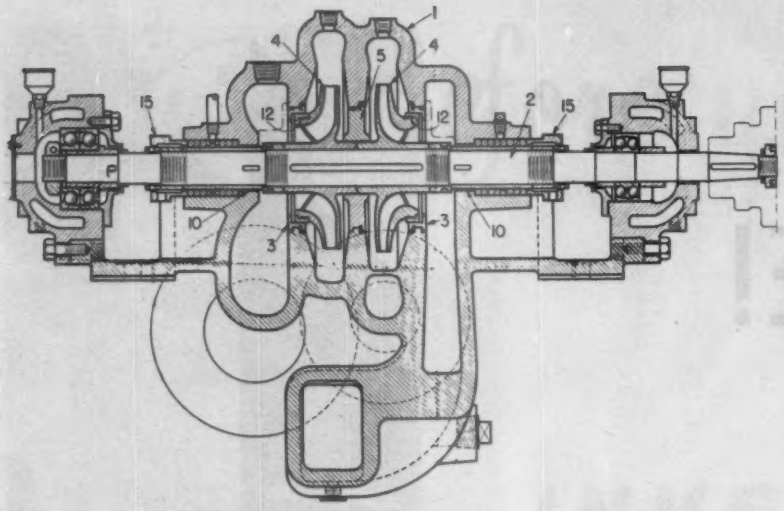


FIG. 3. SECTION of a two-stage pump.

casings if the liquid handled is a strong electrolyte. In such cases, all ferrous materials should be used.

When heated, bronze expands approximately 40 percent more than steel. Because pumps are assembled at normal room temperatures, the original radial clearance between the hub of a bronze impeller and a steel shaft may increase appreciably under operating conditions if the pumping temperature is above normal. This increased clearance can loosen the impeller on the shaft, leading to leakage and erosion.

In addition, it must be remembered that the impeller assembly must be held axially by means of shaft nuts or shaft sleeves, which themselves are fixed on the shaft by means of external nuts. If the axial assembly is made tight under cold conditions, the unequal expansion of the impeller hub and the shaft will cause "crushing" of the bronze impeller hub and may set up severe stresses in the shaft itself. If the assembly is made so as to be tight under operating temperature conditions, the impeller will be loose at low temperatures and there is no possible means to hold it in accurate axial alignment until the pump becomes heated.

Finally, if there are changes in the operating temperature, it would be impossible to keep the assembly tight at all temperatures without setting up excessive stresses. These possibilities are removed when the pump fittings are such that the expansion of the shaft, impellers, and sleeves is equal. For these reasons, bronze is generally not used for pump fittings whenever the temperature of the pumped liquid exceeds 250 F.

There are also limitations placed on the use of bronze impellers by the effect of peripheral speeds. The centrifugal stress exerted on an impeller and the resulting stretch at the impeller hub may become quite appreciable at the higher peripheral speeds used in modern high-head pumps. As an example, a typical 12 in. impeller mounted on a 3 in. shaft and operating at 3,600 rpm will have a stretch of approximately 0.0011 in. for bronze and cast iron. If, in addition to this, the pump handles hot water—say at 250 F—and the impeller is made of bronze, there will be an additional temperature expansion difference of 0.0014 in. resulting in a total looseness of 0.0025 in. between the shaft and the impeller, which would be excessive.

Thus, to avoid the cumulative effect of excessive thermal and centrifugal expansion, the empirical limit to the use of bronze impellers in pumps handling hot liquids is a peripheral speed of approximately 160 ft per sec, or a head of 375 ft per stage.

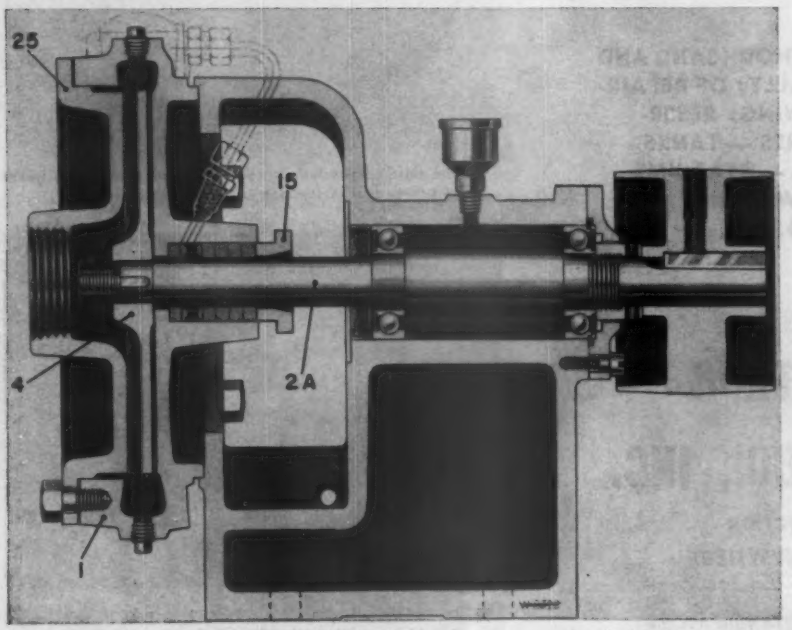
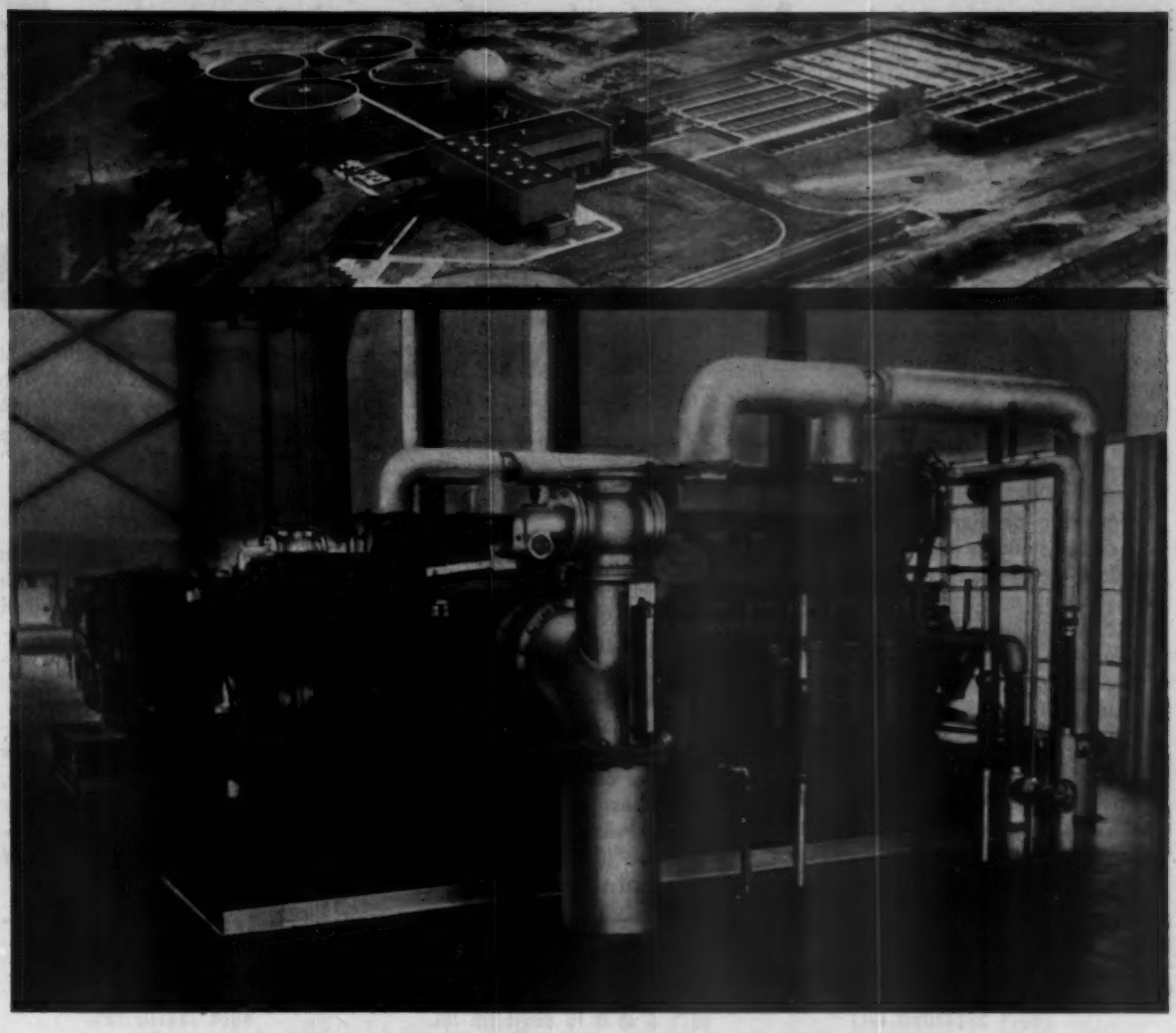


FIG. 4. SECTION of an end-suction, single-stage pump for light duty service.

Wearing Rings, Shafts, Sleeves, etc.

Wearing rings are usually made of bronze for the same reasons as the impellers. However, cast-iron, cast-steel, stainless-steel or monel rings are sometimes used, regardless of whether the impeller itself is made of bronze or of another metal. Such metals are used when hardness or other properties unobtainable with bronze are required.

When shaft sleeves are used the shaft is generally made of open-hearth steel. If high stresses are to be encountered, preference may be given to high tensile strength alloy steels. When corrosive liquids are handled, some seepage may occur either through the pores of the impeller hub or through the joint between the impeller and the sleeves. This is avoided by the use of non-corrosive metals such as stainless steel, phosphor



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bronze, or monel metal. If the pump has no shaft sleeves, the shaft is generally made of stainless steel, phosphor bronze, or monel metals, depending on the liquid to be handled.

A shaft sleeve which protects a shaft in a stuffing box must be made of a material that can be given a smooth finish so that it will operate properly in conjunction with the packing. This is why cast iron is rarely used for shaft sleeves, the majority of them being made of bronze. In applications where bronze sleeves are not satisfactory because of their relative low degree of resistance to abrasion, stainless steel is used. Although a few years ago steel sleeves were more prevalent than stainless steel, the growing popularity and reduced cost of the stainless alloys has caused stainless steel to supersede ordinary steel and, in some services such as boiler feed, even bronze as shaft sleeve material.

Glands are generally made of bronze, although cast iron or steel may be used for all-iron fitted pumps. Where pumps are handling hydrocarbons, iron or steel glands are bushed with bronze to avoid possible sparking, which could ignite inflammable vapors.

Pump Fittings

The expression "pump fittings" is used rather loosely to mean two entirely separate things. In the most accepted sense, it refers to the general construction features of the pump (as for example, "ball-bearing fitted pumps") or to the combination of materials used in the pump, as in "all-iron fitted pump." In a different category (such as when applied in the expression "underwriter fittings") it may refer to various pieces of auxiliary equipment, such as valves, gages, or even tools.

Standard-Fitted Pump

The so-called "standard-fitted" centrifugal pump as defined by the Hydraulic Institute is bronze-fitted. It has a cast-iron casing, steel shaft, bronze impeller and wearing rings, and bronze shaft sleeves, when used. Some manufacturers regularly furnish stainless-steel shafts on pumps without shaft sleeves as standard-fitted pumps.

Various centrifugal pump manufacturers have developed specific material selections for pumps designed for special services. When a pump is so constructed it is generally termed as a "standard pump," although reference is sometimes erroneously made to "standard-fitted pump", even though the materials used do not correspond to the Hydraulic Institute definition.

All-Bronze and All-Iron Pumps

When all parts of a centrifugal pump which come into contact with the liquid pumped are made of bronze, the pump is considered to be an "all-bronze pump."

When all parts of a centrifugal pump which come into contact with the liquid pumped are made of iron or of ferrous metals, the pump is considered to be an "all-iron pump."

Acid-Resisting Pump

An acid-resisting pump is one in which all parts in direct contact with the liquid pumped are constructed of materials that will offer the maximum resistance to the corrosive action of the liquid.

[Note: In Part II, the author discusses certain specific applications and their effect on material selection, as well as the effect of structural features, of the load factor, and of metallurgical advances on the selection of pump materials.]

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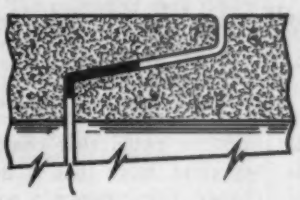
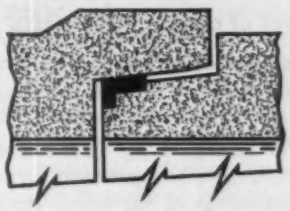
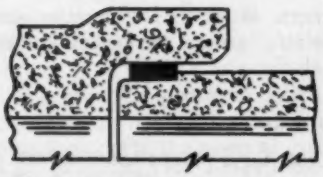


Type "C" Tylox under full compression. Note the visual inspection feature.



Type "C-P" Tylox under full compression. Flanges "lock" Gasket in proper position on the pipe offset.

TYPE "CR" TYLOX For Offset Pipe



Type "CR" Tylox under full compression on single offset pipe.

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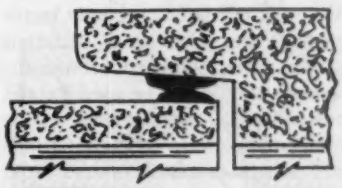

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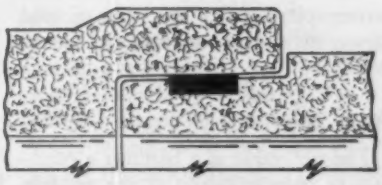

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Pump Materials—*Part II*

by IGOR J. KARASSIK, Consulting Eng. and Manager of Planning Harrison Div., Worthington Corp., Harrison, N. J.

EDITOR'S NOTE: This second of two parts on pump materials discusses liquid characteristics affecting selection of metals for use in centrifugal pump parts and the effect which structural features of certain pump parts, as well as load factors, may have on material selection.

■ IN ADDITION TO THE FACTORS of temperature and pressure, as well as abrasiveness of any solids suspended in the liquid pumped, there are certain specific liquid characteristics which have a significant effect on the adequacy of any metal or combination of metals that can be used in a centrifugal pump. This last article of the series will discuss these characteristics. It will, in addition outline the effect which structural features of certain pump parts and that of load factor may have on material selection.

Effect of pH

The pH value of a liquid is a quantitative representation of the relative acidity or alkalinity of the liquid. It is based on the concentration of H^+ (hydrogen) ions as opposed to OH^- (hydroxil) ions in the solution. The pH scale is a logarithmic scale, calculated from

$$pH = \log \frac{1}{H^+ \text{ Concentration}}$$

which indicates that the lower the pH, the more acid the solution.

A solution having a pH of 7.0 is neutral; pH values above 7.0 indicate alkalinity and pH values below 7.0 indicate acidity. Because the pH value is expressed in a logarithmic scale, it must be noted that changes in pH represent more than a direct linear change. For instance, a solution having a pH of 5.0 is ten times as acid as one having a pH of 6.0.

The pH of a given solution varies with temperature, decreasing rapidly up to 300°F and remaining fairly constant above that. For instance, a solution with a pH of 8.5 at 70°F will have a pH of about 7.0 at 300°F and 6.8 at 500°F (see Fig. 1).

Although pH is not the only factor influencing the selection of materials of pump parts, standard bronze fitted pumps should not be used for pH values below 6.0 or above 8.5 at the pumping temperature. Below 6.0 all-bronze pumps or stainless-steel fitted pumps should be used; above 8.5, the pumps should be all-iron or stainless-steel fitted.

Effect of Galvanic Corrosion

Galvanic corrosion of a metal occurs when the metal is electrically connected to a dissimilar metal and is immersed in an electrolytic solution. The combination of the two metals connected with each other and immersed in an electrolytic solution is the simplest form of electric battery cell. The electrochemical reaction set up under those conditions causes electric current and small metal particles to flow from one metal to the other. These particles may become deposited on the second metal, or may be washed away due to the flow velocities in a centrifugal pump. The protected metal is the cathode and the corroded end is the anode of the two-metal cell. For this reason, the use of dissimilar metals should be avoided in centrifugal pumps when the liquid pumped is an electrolyte.

If metals are arranged in the order of their relative tendency to corrode through galvanic action, the resulting tabulation is termed a "galvanic series." The galvanic series presented in Table 1 gives an approximate idea of the interrelation of metals most commonly used in centrifugal pump construction. The relative position of the listed metals is subject to some changes. However, changes between adjoining groups of metals are unusual.

Salt Water Pumps

Centrifugal pumps handling salt or sea water may be built with standard fittings, that is cast-iron casings and bronze trim, in all iron, all bronze, or with iron casings and stainless fittings, depending on a number of factors.

Thousands of standard fitted pumps are in use handling sea water, but occasionally that type is not suitable, mostly when the sea water is contaminated, as is the case with harbor waters. Failures are usually due to galvanic action between the bronze parts and the cast-iron casing, which graphitizes and is ultimately a total loss. The galvanic action is accelerated under high suction lift condi-

tions, due to the release of oxygen from the water.

Although an all-iron pump apparently avoids the electrolytic action between bronze parts and cast-iron casings, such action may still occur. A certain amount of iron dissolution may take place, leaving graphitized areas, which perform as cathodes to the untouched anodic parts of cast iron. The resulting galvanic action is self-accelerated. To avoid the graphitization and poor resistance to cavitation of cast-iron impellers, these and other small pump parts may be made of stainless steel.

In general, an all-bronze pump should give the longest life for sea water conditions and instances are recorded of all-bronze pumps lasting more than 20 years handling sea or harbor water. Some harbor waters are contaminated by chemicals that make bronze unsuitable.

Effect of Structural Features

Although in many cases the choice of materials can be made mainly from the point of view of corrosion and abrasion resistance, the structural features of a given pump part may play a definite role in the final material selection. Some parts, for instance, may require extremely thin wall sections, for which a material such as cast iron would be unsuitable, even though it may be suitable from the point of view of corrosion. Other parts, such as shaft sleeves, require a high degree of polish. Obviously, only materials capable of receiving such a finish can be used for these parts.

Wherever the structural design features require the use of pressed-on or shrunk-on parts, the material used for these parts must be suitable for this method of mounting. For instance, when pump impellers have to be shrunk on the shaft, bronze cannot be used and the selection is restricted to cast steel or stainless steel.

One of the important factors in the strength of metal castings is the relative uniformity of cross-sections of various portions of the casting. The more uniform these cross-sections, the stronger will be the casting and the less will be the possibility of internal cracks, inclusions, etc. An example of the inter-relation of structural features and material problems is shown in the construction of double-suction impellers (see Fig. 2). The central hub of double-suction impellers is generally cored out, especially in the case of large impellers, in order to avoid the formation of a heavy cross-section which might lead to porous and imperfect castings.

Table I
Galvanic Series of Metals Commonly Used In Pump Construction

Corroded End (Anodic)

- Zinc
- Iron
- Chromium Iron
- Chromium Nickel Iron
- Tin
- Lead
- Brasses
- Bronzes
- Nickel Copper Alloys
- Copper

Protected End (Cathodic)

NOTE: The series is not complete, as it includes only those materials most commonly encountered in centrifugal pump construction. In addition, it does not include the various stainless steels used for pump impellers, wearing rings or sleeves. The position of these metals in the series cannot be definitely fixed as it has been known to change depending on the exact nature of the electrolyte. It is safe to state, however, that with a weak electrolyte such as slightly acid or slightly alkaline water, they will occupy a position in the iron and chrome iron group and that the galvanic action between these metals is almost negligible.

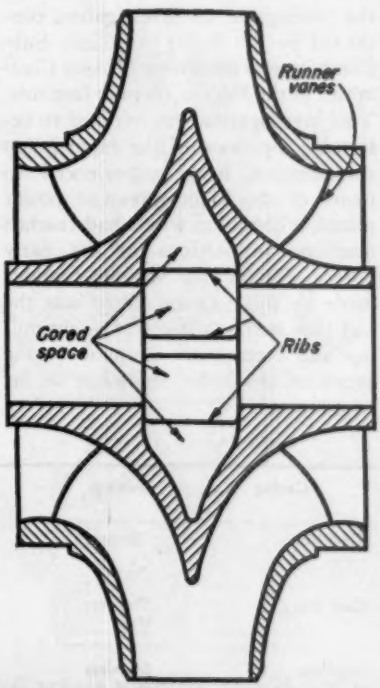


FIG. 2. CORING of impeller hub for foundry reasons.

Effect of Load Factor

It is obvious that the selection of metals that would give the longest possible life for a temporary installation would be uneconomical. Thus, standard fitted pumps may sometimes be applied on a service where corrosion or erosion will wear the pumps out in relatively short time, because the pump would no longer be needed when it is worn out. The same reasoning applies to installations where the pump is operated an extremely small percentage of the time, as long as contact with the liquid pumped during the idle periods does not continue the disintegration process or as long as the pump can be drained and flushed out.

In other words, common sense dictates that the choice of materials be based on considerations of optimum economic life; that is, on the selection of such a combination that the initial cost plus the cost of possible replacement parts and of the necessary labor in replacing these parts yields the lowest over-all total investment during the expected life of the equipment. Thus, in many instances the choice of materials will be neither the cheapest nor the most expensive which may be available.

On the other hand, where outstanding reliability is desired the best materials are none too good, even if a pump is to operate but once in ten years. A good example of this is the pumps used in naval shipboard service. Although operation of the centrifugal pumps on board ship is relatively infrequent in peacetime and not all the equipment installed is operated constantly even in war time, the most rigid specifications as regards materials are enforced because failure of any part of the equipment may prove fatal.

Effect of Metallurgical Advances

There are two fields in which metallurgical advances have had a marked effect on centrifugal pump design. These are the pumpage of chemicals and the handling of boiler feed water. The selection of materials for centrifugal pumps handling chemicals is naturally dependent on the particular liquid in question. This service is a specialized field and one can general-

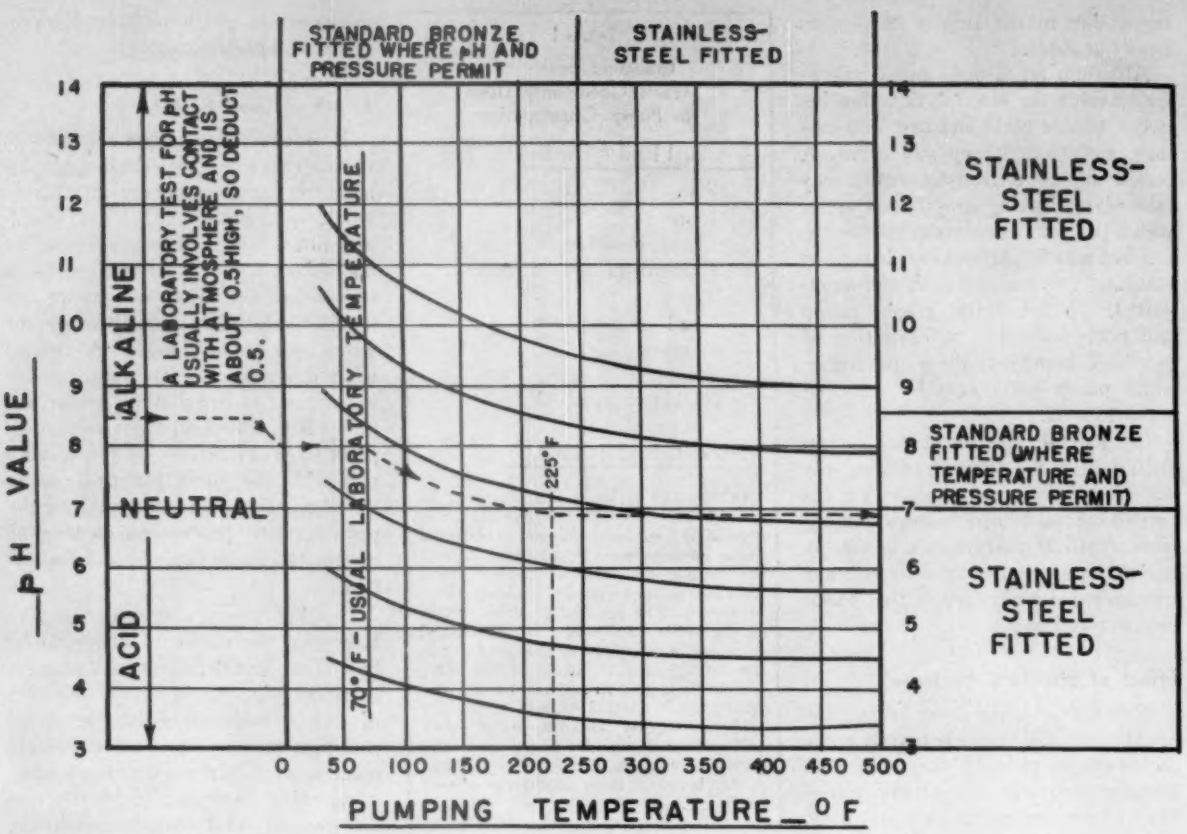


FIG. 1. EFFECT of temperature on pH and boiler feed pump material recommendations.

ly obtain detailed information from the manufacturers actively engaged in production of chemical pumps.

Boiler feed pumps present a more general interest and as the selection of materials for this type of pump has been the most affected of all the general classes of centrifugal pumps by metallurgical developments of the last 15 years, it may be interesting to discuss the present trends in boiler feed pump material selection.

Most boiler feed pumps designed for pressures of 800 psi and above are now stainless-steel fitted, regardless of temperature or feedwater analysis. The use of stainless steel for impellers, wearing rings, sleeves, etc., shows signs of extending to even lower pressures. Today it is almost mandatory under all pressure conditions for temperatures over 250°F and for all installations where the feedwater pH is either below 7.0 (neutral) or over 8.5.

Since approximately 1944, in addition to the use of stainless steels for the internal parts of centrifugal boiler feed pumps, stainless steel casings have been utilized to a much greater extent than before. A definite impetus in this direction had been given by the findings of an investigation conducted by the Boiler Auxiliary Sub-Committee of the Prime Movers Committee of the Edison Electric Institute. This investigation was initiated to determine the cause of the rapid pump deterioration being experienced in many of the higher-pressure power plants, a condition which had reached alarming proportions in the early 1940's. Among the various findings made by this sub-committee was the fact that stainless steels (5% chromium and better) are immune to the attack of any boiler feedwater so far encountered.

The following table has been prepared as a general guide for the selection of boiler feed pump materials:

Generally, straight chromium steels are used, with chromium content at the 5, 9, or 13% level. Austenitic chromium-nickel steels (18% chromium, 8% nickel; or the higher 25% chromium, 20% nickel type) are not practical for boiler feed service. Austenitic steels have a coefficient of expansion approaching that of bronze and 40% greater than that of either carbon steel or of the lower chromium content steels. This difference in coefficient of expansion would lead to operational difficulties if the pump handles hot water.

Casing	Fittings	Max. Temp.	Use
Cast iron	Bronze	250°F	pH neutral to 8.5, unless water is known to have corrosive action.
Cast iron	Stainless steel	350°F	Any pH, unless water is known to have excessive corrosive action
Stainless steel	Stainless steel	Any temp. normally encountered	Any pH and where water is corrosive or previous trouble reported

Vertical Pumps—*Part I*

by IGOR J. KARASSIK, Consulting Eng. and Manager of Planning, Harrison Div., Worthington Corp., Harrison, N. J.

EDITOR'S NOTE: This first of three parts on vertical pumps gives the reasons for selection of this type of arrangement and discusses the installation of such equipment in dry-pit applications. The two other parts included under the same heading deal with wet-well (submerged) applications and with servicing and maintenance of both types.

■ A LARGE AND IMPORTANT portion of the field of application of centrifugal pumps utilizes units arranged with vertical shafting. And although the basic elements of a centrifugal pump are essentially similar regardless of the position of the shaft, it is obvious that they must vary in their execution, depending on whether the shaft is vertical or horizontal. The preceding group of articles dealt primarily with horizontal pumps and their individual structural elements. This and the following two articles will discuss details of construction which apply specifically to vertical arrangements.

Preference for a vertical arrangement may be based on several factors. In a few cases the vertical design is preferred because of the advantages of reduced floor space, as in the case of marine pumps. In other cases it is desirable to mount the pump at a low

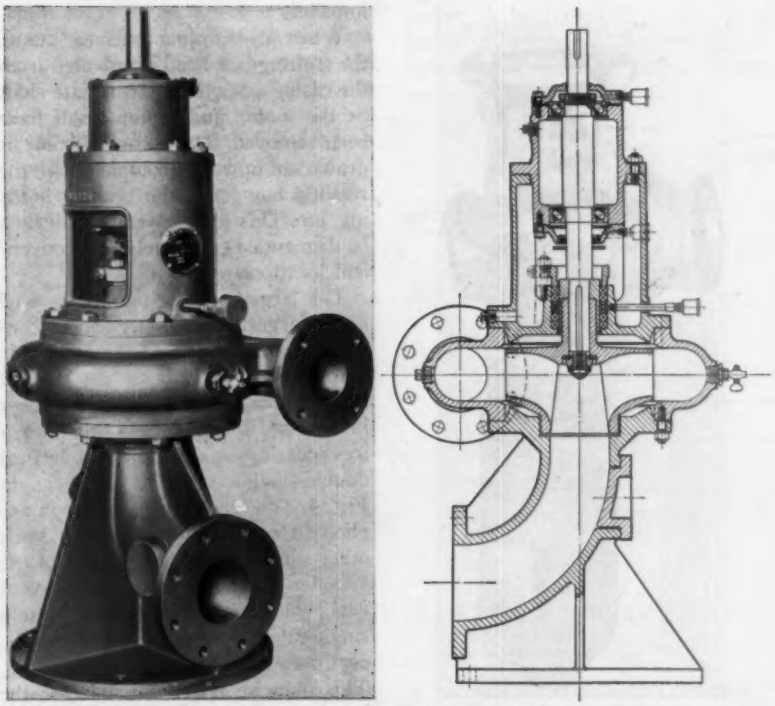


FIG. 1. TYPICAL small-capacity vertical sewage pump for drive through intermediate shafting.

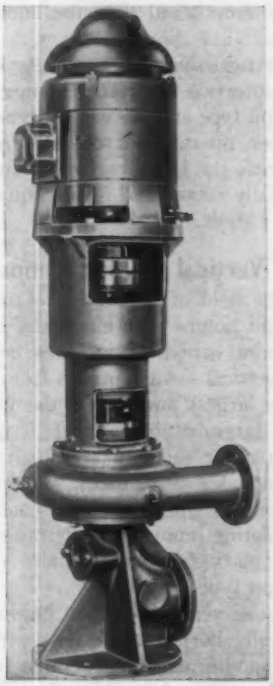


FIG. 2. VERTICAL sewage pump similar to Fig. 1, but with direct-mounted motor.

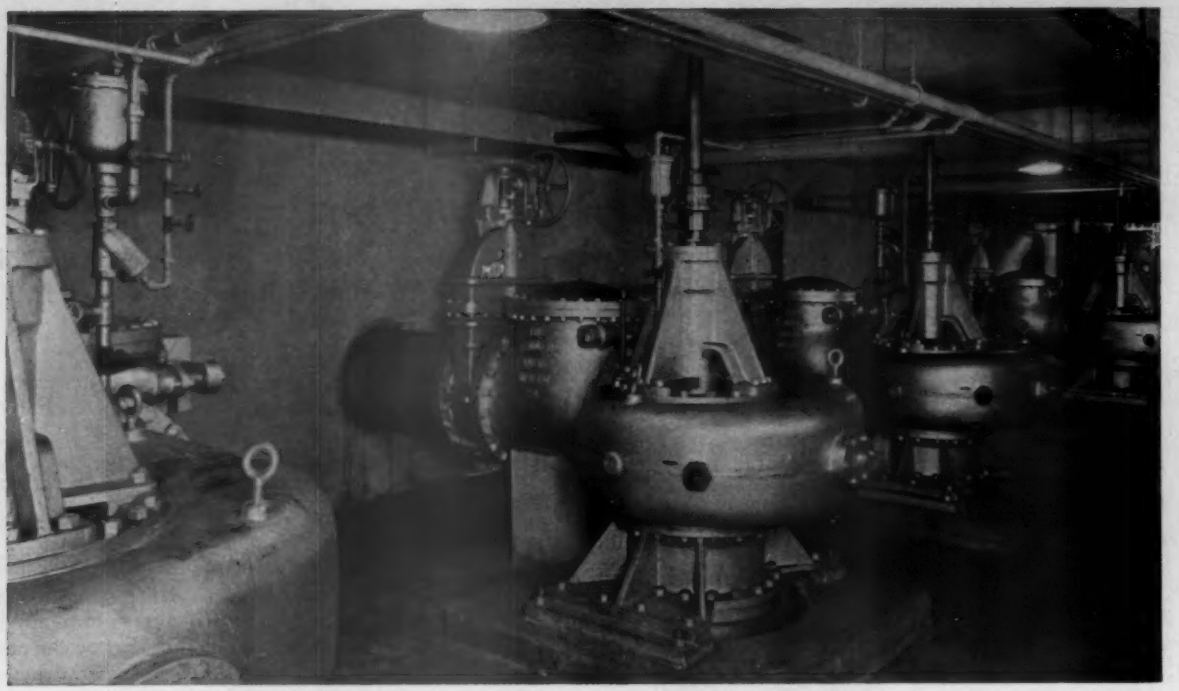


FIG. 3. INSTALLATION of vertical bottom-suction volute pumps with piloted couplings.

elevation because of suction conditions, but also preferable or necessary to have the driver at a high elevation. The vertical type is generally used for very large capacity pumps because, when all factors are considered, it is more economical than the horizontal type.

Vertical shaft pumps can be classified into two separate groupings: the dry-pit type and the wet-pit type. The former operate surrounded by air, whereas the latter are either fully or partially submerged in the liquid that they handle.

Vertical Dry-Pit Pumps

The field of application of vertical dry-pit pumps with external bearings is quite varied. It includes most of the vertical sewage pumps from small to the largest, and most of the medium and large drainage and irrigation pumps, for medium and high head. It includes also many water supply pumps and many large condenser circulating pumps. Finally, most vertical marine pumps are also of the dry-pit type.

Some vertical dry-pit pumps are basically horizontal designs with minor modifications, generally in the bearings, to adapt them for vertical shaft drive, such as shown in Fig. 5. The reverse is true for small- and meduim-size sewage pumps, as the vertical type is the most popular for that service. Most of these small- and medium-size sewage pumps have elbow suction nozzles (Figs. 1 and 2)

FIG. 4. VERTICAL double-suction volute pump with direct-mounted motor.

as the suction supply is usually taken from a wet well adjacent to the pit in which the pump is installed. Generally, the suction elbow contains a handhole with a removable cover in order to provide easy access to the impeller.

When dismantling such a pump, the stuffing box head is unbolted from the casing after the intermediate shaft or the motor and motor stand have been removed. The rotor assembly is drawn out upwards, complete with the stuffing box head, the bearing housing, etc. This rotor assembly can then be dismantled completely at a convenient location.

The larger sewage pumps, as well as the larger drainage, irrigation, condenser circulating and water supply pumps, are generally of the vertical bottom-suction type (Fig. 3). Except for sewage service, these other services occasionally can employ a vertical double-suction type of pump, as in Fig. 4. When a vertical pump is applied to condensate service or some other service for which the eye of the impeller must be vented to prevent vapor binding, a pump with bottom single-inlet impeller is not desirable, as it does not permit effective venting. This likewise is unattainable for the lower eye in a vertical pump employing a double-suction impeller. For

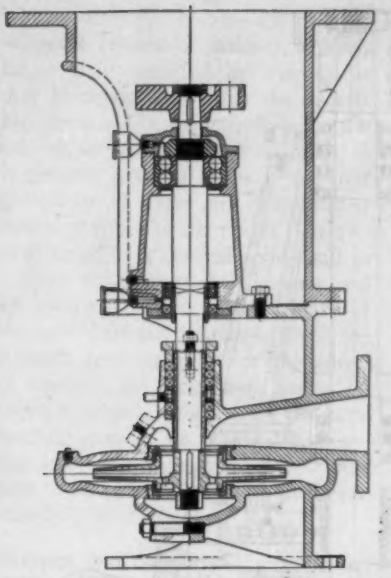


FIG. 5. SECTION of vertical pump with top-suction impeller.

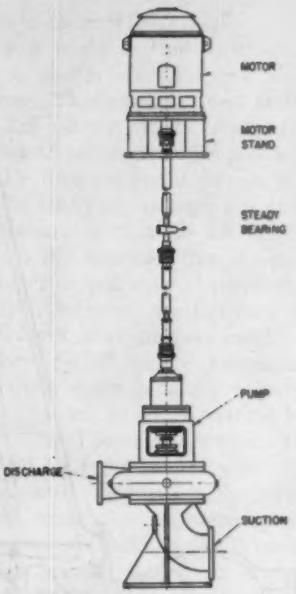


FIG. 6. TYPICAL elevation of vertical pumps with tubular shafting.

FIG. 7. TYPICAL elevation of vertical pump and solid shafting with motor supporting rotating parts.

such vertical pumps the most suitable design would be one with a top single-inlet impeller, as shown in Fig. 5.

Driver Location and Connection

When the driver of the vertical dry pit pump can be located immediately above the pump, it is often supported on the pump itself, as in Figs. 2 and 4. The shafts of the pump and the driver may be connected by a flexible coupling, in which case each must have its own thrust bearing. In other cases the pump shaft is rigidly coupled to the driver shaft or is an extension of the driver shaft and a common thrust bearing is used, generally in the driver.

When the driver of a vertical pump is to be mounted some distance above the pump, intermediate shafting must be used to connect the two. The design of this shafting depends on the power to be transmitted, the speed, the total length, and the bearing design used in the pump and in the motor.

The shafting connecting a small- or medium-size centrifugal pump with its driver is now usually of the universal-joint type with hollow tubing (Fig. 6). The lower section has a universal joint at both ends, whereas each upper section (if more than one section is used) has a single bearing supporting the lower end and a universal joint at the upper end. This type of shafting compensates for angular misalignment and, as the lower section

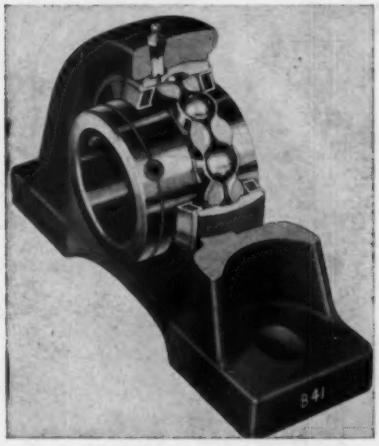


FIG. 8. TYPE of ball bearing used as intermediate shaft steady bearing in smaller units.

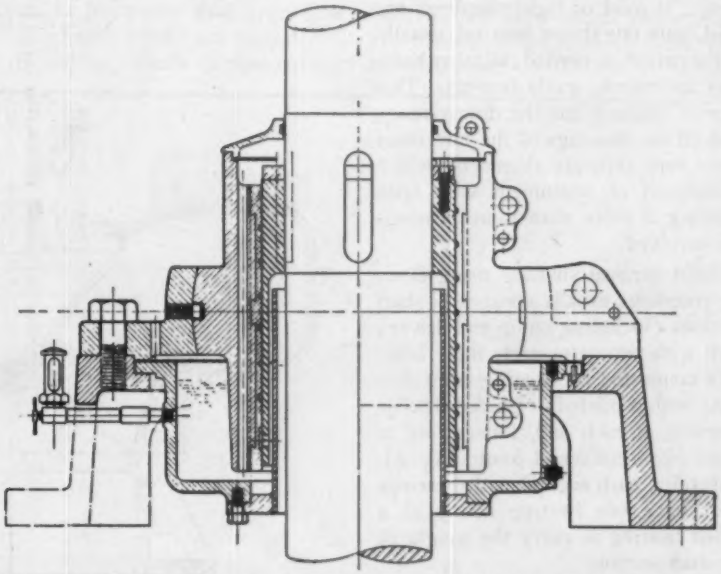


FIG. 9. SELF-OILING type of steady bearing used for large vertical shafting.

also incorporates a splined joint, also compensates for any minor discrepancy in length. When speed permits, shaft sections up to 120 inches or more in length can be obtained. Sections longer than 10 feet are easily sprung and must be handled carefully.

This shafting does not transmit thrust, so the pump and driver must each have a thrust bearing. Usually the driver is supported above the supporting floor on a stand, permitting access to the flange connection and upper universal joint for bolting up the flanges and relubrication. The driver must be of the solid-shaft type or, if of the hollow-shaft type, must be provided with a head shaft guided by a lower bearing to act in the same capacity.

Except for the lowest universal joint, the weight of this shafting is carried on the motor. Except for extremely long shafting installations, the total weight involved is relatively small and a normal thrust motor can be used. Actually this is a more expensive type of shafting than solid shafting. However, because the basic universal joint has a larger field of application on automobiles and trucks, it is a production item and the increase in cost over solid shafting is very reasonable.

For intermediate shafting of units requiring more torque than can be carried by the available sizes of universal-joint type of shafting, solid shafting is used, either with solid couplings or with flexible-type couplings. If solid or rigid couplings are used, only one thrust bearing, usually in the driver, is needed; all other bearings are merely guide bearings. This type of shafting has the disadvantage that all the bearings of the unit must be in very accurate alignment, which is difficult of attainment with open shafting if more than three bearings are involved.

Solid vertical shafting using flexible couplings usually consists of shaft sections (including pump and driver) each with two or possibly three bearings connected by floating shaft sections with a piloted or guided flexible coupling at each end, thus acting in effect like a universal joint (Fig. 3). Naturally, each section with bearings must have one bearing acting as a thrust bearing to carry the weight of the shaft section.

The intermediate shafting for large pumps which require large shafts is usually of the solid type with solid couplings of the flanged type. In many cases these are forged onto the shaft sections (Fig. 7).

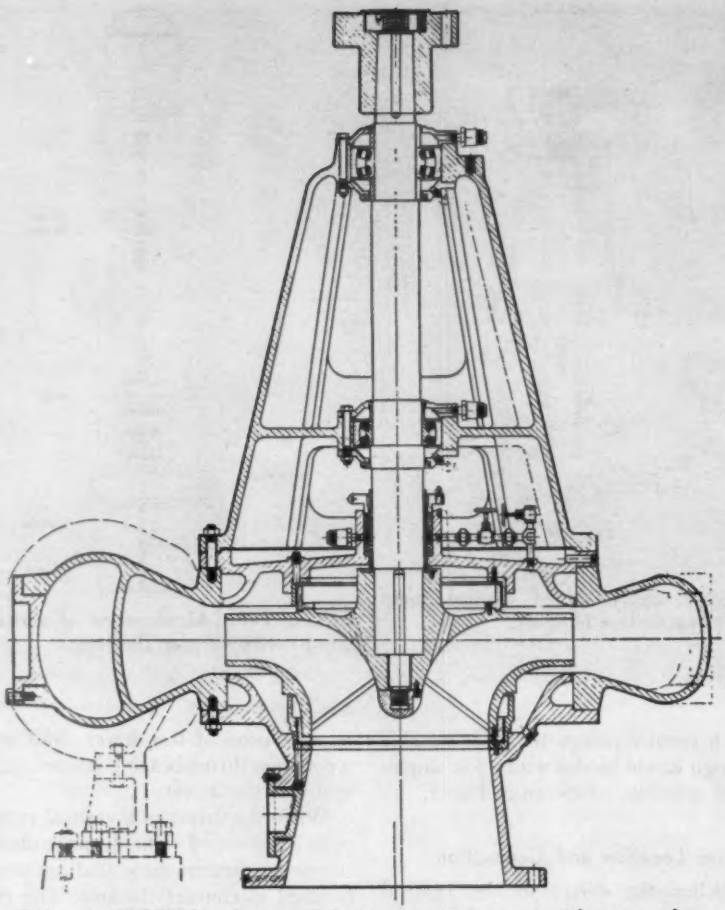


FIG. 10. SECTION of vertical bottom-suction pump with twin volute.

The size of the shafting to be used for an installation may be determined by the torque to be transmitted. However, if a certain span between bear-

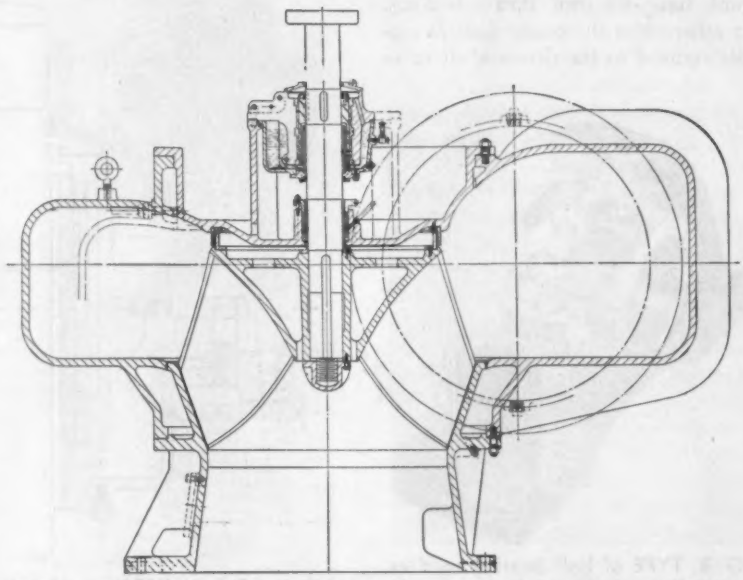


FIG. 11. SECTION of large vertical bottom-suction volute pump with single guide bearing at pump.

ings is desirable because of existing supports (floors or beams), a shaft larger than required by the torque may be necessary so that the operating speed will be sufficiently below the critical speed. In this connection, it is general practice to have the first critical speed above any operating or runaway speed of the pump. The critical speed of a vertical solid shaft is a direct function of the diameter and an inverse function of the square of the span between bearings. Thus, for a shaft running at twice the speed of another, the first shaft has to be twice as large in diameter for the same bearing span or its permissible bearing span will be reduced to 70 percent of that permissible with the lower speed.

Bearings and Supports

The bearings for vertical dry-pit pumps and for intermediate guide bearings are usually of the anti-friction type, grease-lubricated to simplify the problem of retaining the lubricant in a housing having a shaft projecting vertically through it (Fig. 8). In larger units where anti-friction bearings are not available or desirable, self-oiling babbitt bearings or forced-feed-oil babbitt bearings with a separate oiling system are used (Fig. 9).

It is important that the supports for the guide bearings of vertical shafting connecting a centrifugal pump and its driver be sufficiently rigid. The radial load is usually assumed to be the same as if the unit were in a horizontal position. With this loading, the deflection of the supports in any direction should not exceed

$$\Delta = (187.7/n_c)^2$$

where Δ is the deflection, in inches, and n_c is the critical speed of the shafting. This critical speed is usually 125 percent of the pump rotative speed or some value above the possible runaway speed, in case there may be backflow through the pump.

If beams or channels are used to support the bearings, the design of the latter is naturally dependent on the span between the bearings, the radial force, and the permissible deflection. Small pump installations with short spans generally require a single channel, to which vertical surface-mounted bearings are most easily attached. Larger units with long spans often require fairly widely spaced channels or beams with strengthening lattice work. With this type of bearing support, a horizontally-mounted guide bearing resting directly on the beams or on a bridging plate is more convenient. These considerations lead to a tendency to use vertically-mounted guide bearings for smaller units and horizontally-mounted guide bearings for larger units.

Structurally, vertical dry-pit centrifugal pumps are similar to pumps with horizontal shafts. It is to be noted however, that many of the very large vertical single-stage single-suction (usually bottom) volute pumps (which is the preferred type for large storm water pumpage, drainage, irrigation, sewage and water supply-projects) have no comparable counterpart in the horizontal-shaft type. The casings of such pumps are basically of the U section, which is structurally weak, often necessitating heavy ribbing in order to make the casing sufficiently rigid. In comparable water turbine practice, a set of vanes (called a speed-ring) is employed between the casing and the runner to act as struts. Although such a speed-ring does not affect the operation of a water turbine adversely, it would function basically as a diffuser in a pump, with the inherent hydraulic limitations of that construction. Some of the high-speed large pumps of this type have been made in the twin-volute design. The wall separating the one volute and the passageway of the other from the tip of the volute to the discharge nozzle acts as a strengthening rib for the casing, thus making it easier to design a casing strong enough for the pressure involved (Fig. 10).

Vertical pumps with bottom single-inlet impellers (Figs. 1 and 10) have a leakage joint between the wearing ring hub of the impeller and the suction head. When pumps of this type are handling gritty liquids the grit separates out during periods of shutdown and concentrates at or near this joint. When the pump is again started, this concentration of grit is washed through the leakage joint, with resulting wear. With large pumps, a ring construction (as shown in Fig. 11) is feasible; this involves extending the stationary ring above the suction head, forming a pocket in which the grit will be deposited and from which it can be flushed periodically. These and other refinements are feasible in large pumps, but not in small ones.

Vertical Pumps — *Part II*

by IGOR J. KARASSIK, Consulting Eng. and Manager of Planning, Harrison Div., Worthington Corp., Harrison, N. J.

EDITOR'S NOTE: This second of three parts on vertical pumps deals with wet-pit units of both turbine and propeller (or modified propeller) types. The previous part dealt with dry-well units, as well as driver mounting and shaft selection and mounting. Part III deals with wet-pit sewage, volute, and sump pumps.

■ VERTICAL PUMPS intended for submerged operation are manufactured in a great number of different designs, depending mainly on the service for which they are intended. Thus, wet-pit centrifugal pumps can be classified as follows:

1. Verical turbine pumps.
2. Vertical wet-pit propeller or modified propeller pumps.
3. Wet-pit sewage pumps.
4. Wet-pit volute pumps.
5. Sump pumps.

Vertical Turbine Pumps

Vertical turbine pumps were originally developed for pumping water from wells; they have been called deep well pumps, turbine well pumps, or borehole pumps. As their application to other fields has increased, the name "vertical turbine" pumps has been generally adopted by the manufacturers. (This is not too specific a designation because the term "turbine" pump has been applied in the past to any pump employing a diffuser. There is a tendency to designate pumps using diffusion vanes as "diffuser" pumps, as against "volute" pumps. As that designation becomes more universal, applying the terminology of vertical turbine pumps to the construction formerly called turbine well pumps will become more specific.)

The largest field of application for this type of pump is pumping from wells for irrigation and other agricultural purposes, for municipal water supply and for industrial use for processing, circulating, refrigerating and air conditioning water supplies. In addition, this type of pump has

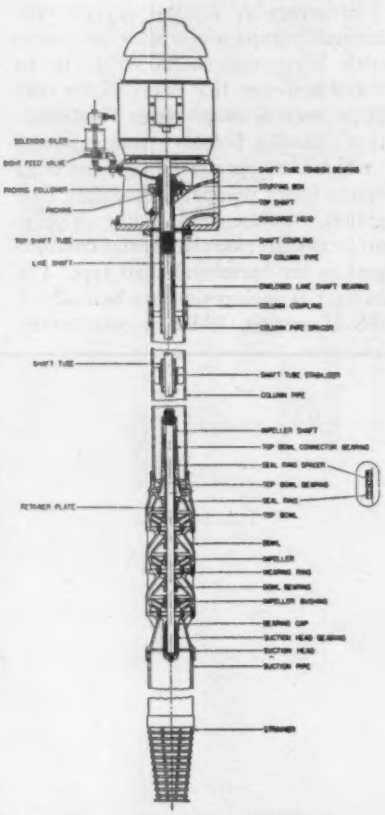


FIG. 1. SECTION of vertical turbine pump with closed impellers and enclosed line shafting for oil lubrication.

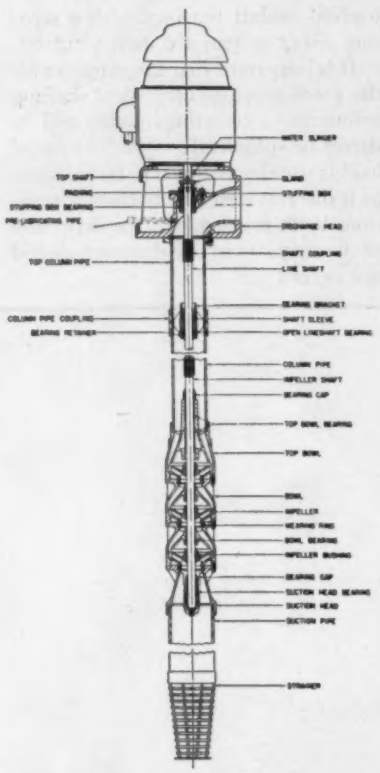
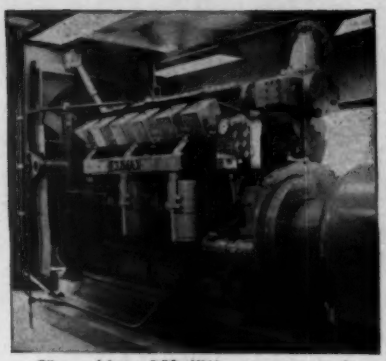
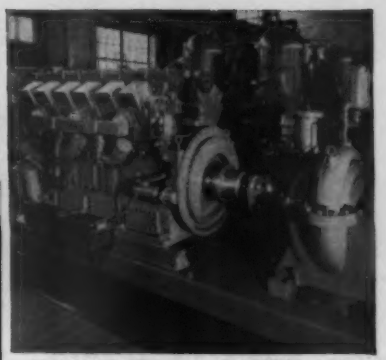


FIG. 2. SECTION of vertical turbine pump with closed impellers and open line shafting for water lubrication.



Climax-driven 250 KW generator in St. Petersburg, Florida, water treatment plant protects against power failure.

Eight of fourteen Climax V-12 500 hp. engines powering storm water pumps for City of Saginaw, Michigan.



Model V-12 Climax engine in high capacity centrifugal pump service in a city water plant.

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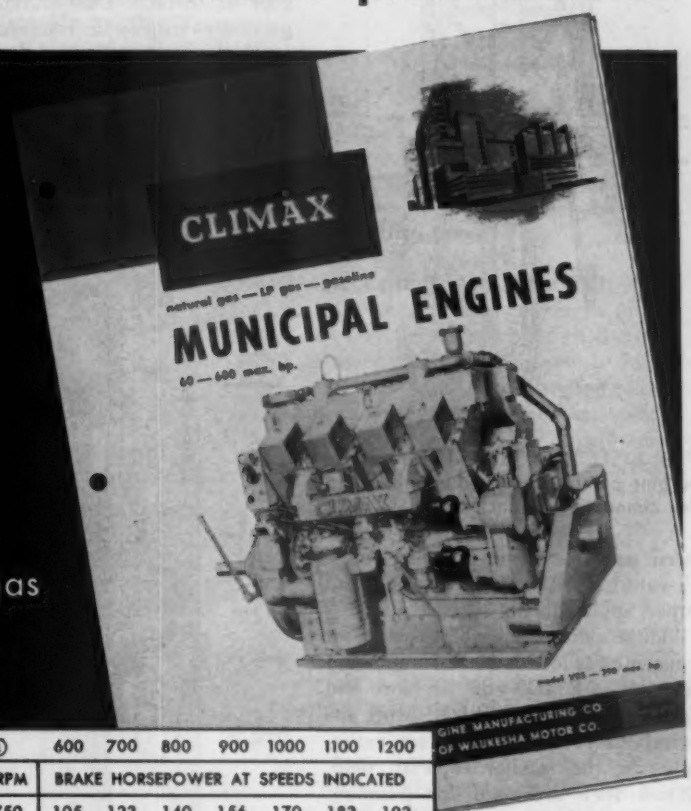
LP gas • gasoline
60 to 600 max. hp.



BASIC MAX. ENGINE HP (Natural Gas and Gasoline) ①					600	700	800	900	1000	1100	1200
MODEL	No. of Cyls.	Bore & Stroke	Displ.	Torque @ RPM	BRAKE HORSEPOWER AT SPEEDS INDICATED						
R-165	6	6⅛ x 7	1238	930 @ 750	105	123	140	156	170	183	192
K-67	6	7 x 7	1616	1240 @ 805	140	165	188	210	230	248	265
K-75	6	7½ x 7	1855	1410 @ 800	160	186	214	240	265	286	304
V-80	8	7 x 7	2155	1610 @ 850	178	210	241	272	300	323	340
V-85	8	7½ x 7	2474	1860 @ 900	207	249	285	317	345	370	390
V-122	12	7 x 7	3232	2440 @ 900	280	330	380	420	460	490	520
V-125	12	7½ x 7	3711	2880 @ 850	310	370	435	490	540	580	605

① Basic engine includes ignition, maximum carburetion, and water pump. Ratings indicate maximum horsepower.

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DIVISION OF WAUKESHA MOTOR COMPANY

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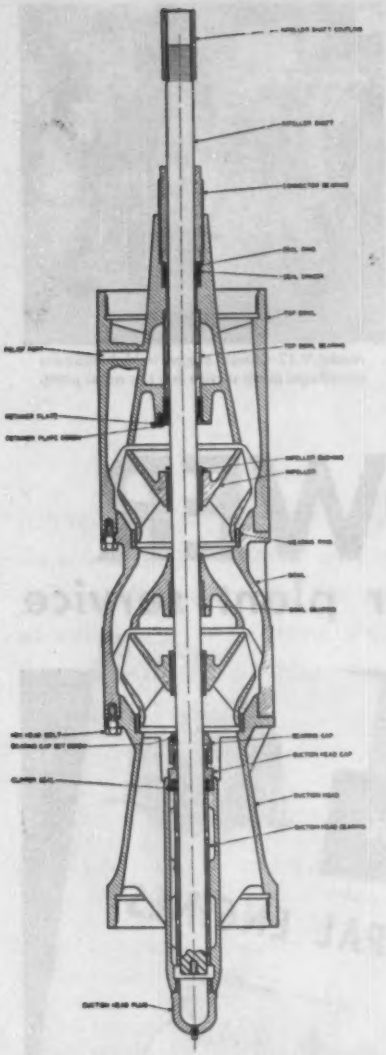

FIG. 3. SECTION of bowl of a vertical turbine pump with closed impellers and for connection to enclosed shafting.

been used for brine pumping, mine dewatering, oil field repressuring, and other applications.

These pumps have been made for capacities as low as 10 or 15 gpm and as high as 25,000 gpm or more and for heads up to 1,000 feet. Most applications of these pumps are naturally for the smaller capacity field. When they are used for pumping from bored wells, the capacity is naturally limited by the physical size of the well in which the pump will be installed, as well as by the rate at which water can be drawn from the well without lowering the water level to the point where there is insufficient submergence.

In a vertical turbine pump it is desirable to have a provision so that the shaft can be readily raised or lowered from the top, in order that the position of the impeller in the bowl can be adjusted properly. In addition, it is necessary to have an adequate thrust bearing to support the vertical shafting, the impellers, and the hydraulic thrust developed when the pump is in service. As the driving mechanism must also have a thrust bearing to support its vertical shaft, it is usual to provide a thrust bearing of adequate size in the driving mechanism to carry the pump parts as well. For these two reasons, the hollow-shaft type of motor or gear is most generally used for vertical turbine pump drive. In addition to the hollow shaft motor or gear drive, these pumps are sometimes built with their own thrust bearings for belt drive and for drive through a flexible coupling by a solid shaft motor, gear or turbine. Dual-driven pumps generally employ a combination of an angle gear with a vertical motor mounted on top of the gear.

Structurally, the design of vertical pumps illustrates how a centrifugal pump design can become specialized to meet a specific application. Fig. 1 shows one design with closed impellers and enclosed line shafting;

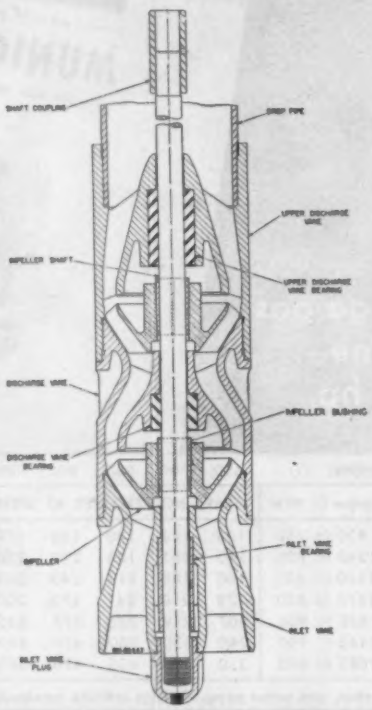

FIG. 4. SECTION of bowl of a vertical turbine pump with open impeller and for connection to open line shafting.

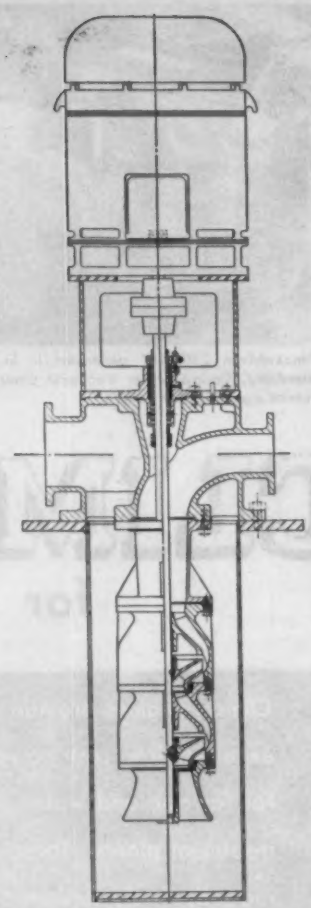

FIG. 5. SECTION of a vertical turbine "can" pump for condensate service.

Fig. 2 shows another design with closed impellers and open line shafting.

The bowl assembly or section consists of the suction case (also called suction head or inlet vane), the impeller or impellers, the discharge bowl, the intermediate bowl or bowls (if more than one stage is involved), the discharge case, the various bearings, the shaft, and the various miscellaneous parts (keys, impeller locking devices, etc.)

The column pipe assembly consists of the column pipe itself, the shafting above the bowl assembly, the shaft bearings, and the cover pipe or bearing retainers. The pump is suspended from the driving head, which consists of the discharge elbow (if above-ground discharge), the motor or driver support, and either the stuffing box (in case of open shaft construction) or the assembly for providing tension on the cover pipe and for providing the introduction of lub-

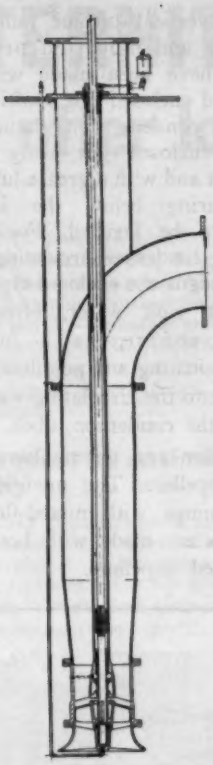

FIG. 6. SECTION of a vertical propeller pump with below-ground discharge.

ricant to the cover pipe. In case of below-ground discharge, the discharge is taken from a tee in the column pipe and the driving head functions principally as a stand for the driver and the support for the column pipe.

In a vertical turbine pump the liquid is guided into the impeller by the suction case or head. This may be a bell mouth (as in Fig. 5) or a tapered section (as in Figs. 3 and 4) for attachment of a conical-type strainer or a suction pipe.

Semi-open and closed types of impellers are both commonly used. For proper clearances in the various stages the semi-open type requires more care in assembly on the impeller shaft and requires more accurate field adjustment of the vertical shaft position in order to obtain the best efficiency. In addition, enclosed impellers are favored over semi-open because wear on semi-open impellers reduces capacity, which cannot be restored unless new impellers are installed.

Normal wear on enclosed impellers does not affect impeller vanes, and worn clearances may be restored by replacing wearing rings. The thrust produced by open impellers may be as much as 150 percent greater than with enclosed impellers, due to the relative unbalanced thrust characteristics of the two styles.

Occasionally in power plants, especially in cases where a unit is to be installed in an existing plant in a space originally allotted for a smaller size unit, the maximum level that can be carried in the condenser hotwell will not give adequate NPSH (net positive suction head) for conventional horizontal condensate pump mounted on the basement floor. To build a pit for a conventional horizontal condensate pump or a vertical dry-pit type in order to provide sufficient submergence would involve considerable expense. In some cases vertical turbine pumps of the design shown in Fig. 5 have been used. This is basically a vertical turbine pump mounted in a tank (often called a can) sunk into the floor. The length of the pump must be such that sufficient NPSH is available for the first-stage impeller design; the diameter and length of the tank must allow proper flow down the space between the pump and tank and then turn and flow into the bell mouth. Installation of such a design in an existing plant is naturally much less expensive than making a pit, as the hole necessary to install the tank is much smaller. This same basic design has found some application in cases of pumps handling volatile liquids where the layout of equipment does not provide sufficient NPSH for pumps mounted on the operating floor.

FIG. 7. VERTICAL propeller pump.

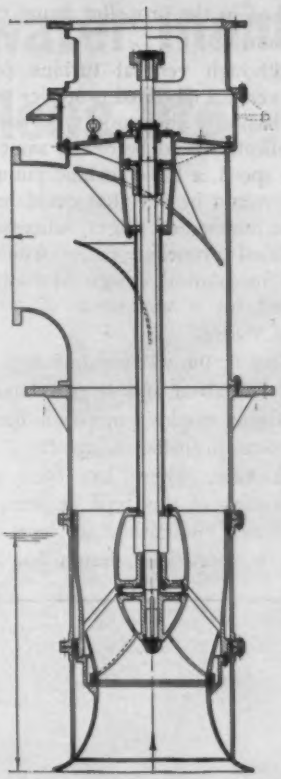

FIG. 8. SECTION of vertical modified propeller pump with removable bowl and shafting assembly.

Vertical Propeller Pumps

Originally the term vertical propeller pump was applied to vertical wet-pit diffuser or turbine-type pumps using a propeller or axialflow-type impellers, usually installed in an open sump and having a relatively short setting. For operating heads in excess of those which can be met with a single-stage axial-flow impeller, two or more stages might be used or a single-stage lower specific speed type of pump with a mixed-flow impeller might be used. If the operating head is high enough, a pump with mixed-flow impellers in two or more stages might be used. For lack of a suitable name, these higher head designs have been more or less generally consid-

ered as in the propeller pump classification.

Although vertical turbine pumps and vertical modified propeller pumps are basically the same type and hydraulically could be of the same specific speed, a basic turbine pump design would be one that could have a large number of stages, whereas the modified propeller pump would be of a mechanical design basically intended for a maximum of two or three stages.

Most of the wet-pit drainage, low-head irrigation and storm water installations employ pumps of the conventional propeller or modified propeller type. There has been some application of this type of pump for condenser circulating service; however, a specialized design has been primarily used for this field. Large power plants generally are located at centers of population, and as a result frequently have to use badly contaminated water, both fresh and salt, as a cooling medium. With such water, a fabricated steel column pipe and elbow would give short life, and cast iron, bronze, or even a more corrosive resisting cast metal, must be used. This results in a very heavy pump when large capacities are involved. To avoid the necessity of lifting this large mass when the rotating parts need maintenance, some designs (one of which is illustrated in Fig. 8) are built so that the impeller, diffuser and shaft assembly can be removed from the top without disturbing the column pipe assembly. These designs are commonly designated as of the "pull-out" type.

Like vertical turbine pumps, the propeller and modified propeller pumps have been made with both open and enclosed line shafting. Except for condenser circulating service, the enclosed type, using oil as a lubricant and with a grease-lubricated tail bearing below the impeller, seems to be favored. For pumps handling condenser circulating water, some designs use enclosed-type shafting, but with water, often from another source, as a lubricant, thus eliminating any possibility of oil getting into the circulating water and coating the condenser tubes.

Propeller-type pumps have open-type propellers. The modified propeller pumps with mixed-flow-type impellers are made with both open and closed impellers.

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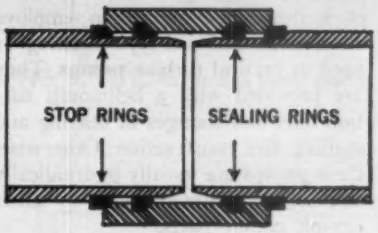

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Vertical Pumps — *Part III*

by IGOR J. KARASSIK, Consulting Eng. and Manager of Planning, Harrison Div., Worthington Corp., Harrison, N. J.

EDITOR'S NOTE: This third of three parts on vertical pumps deals with wet-pit sewage, volute, and sump pumps. The previous sections dealt with driver mounting, shaft selection and mounting, dry-well units, and wet-pit units of turbine propeller, and modified propeller types.

Wet-Pit Sewage Pumps

Except for some large vertical propeller-type pumps handling dilute sewage (basically storm water contaminated by domestic sewage), vertical wet-pit sewage pumps are of the bottom-suction volute type with impellers capable of handling solids and stringy materials with minimum clogging. This type pump is usually suspended from a higher floor by means of a drop pipe and often employs covered or enclosed-type shafting as used in vertical turbine pumps. They are provided with a bellmouth suction inlet and changes in bearing and stuffing box construction. Otherwise, these pumps are usually hydraulically and mechanically similar to their dry-pit counterparts.

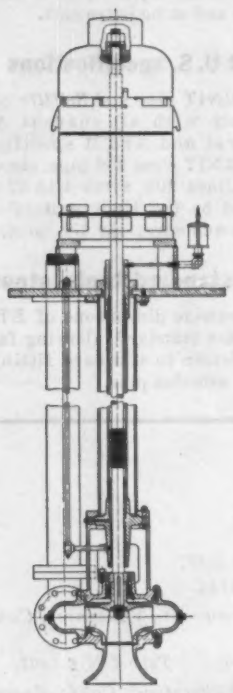


FIG. 1. SECTION of vertical wet-pit sewage or non-clogging pump.

Three basic constructions have been used for this type of pump. The first, with impellers without back rings, employs a water-or grease-lubricated bearing with a seal at its lower end, immediately above the impeller. The upper end is vented to the suction pit to prevent any appreciable hydraulic pressure on the seal at the lower end of the shaft cover pipe; otherwise, water will work into the cover pipe. The seal at the lower end of the impeller bearing must be effective, especially with high pump heads; otherwise, there will be considerable leakage of water through the bearing, with some cutting if grit is present in the liquid. A second construction is similar, but employs pump-out vanes or wearing ring joints on the back side of the impeller (the latter necessitating balance holes through the impeller hub), so that the bearing is subjected only to suction pressure. A third type of construction, used primarily with impellers having no back rings or pump-out vanes, retains a stuffing box in some form, with bearings above the stuffing box and separated from it.

Although shaft seals and packing used to seal the lower end of the cover pipe or bottom bearing are intended to exclude water as much as possible, some leakage of liquid with higher suction water levels is to be expected, even when the seal is new. Some of the shaft bearings may have

FIG. 2. TYPICAL cellar drainer sump pump.

Courtesy Starite Co.

to operate in water or in a mixture of oil and water, so that the bearing may wear relatively faster than one positively lubricated with oil or grease. In general, wet-pit sewage pumps should be limited to services requiring operation for a very limited period of the day.

Wet-Pit Volute Pumps

In addition to the more common wet-pit sewage pumps previously discussed, which are also volute pumps, there have been various installations of volute pumps: some single suction, with either bottom or top suction; others double suction, supported on the pit floor. Except for some floating drydock installations, this type of pump has little modern application.

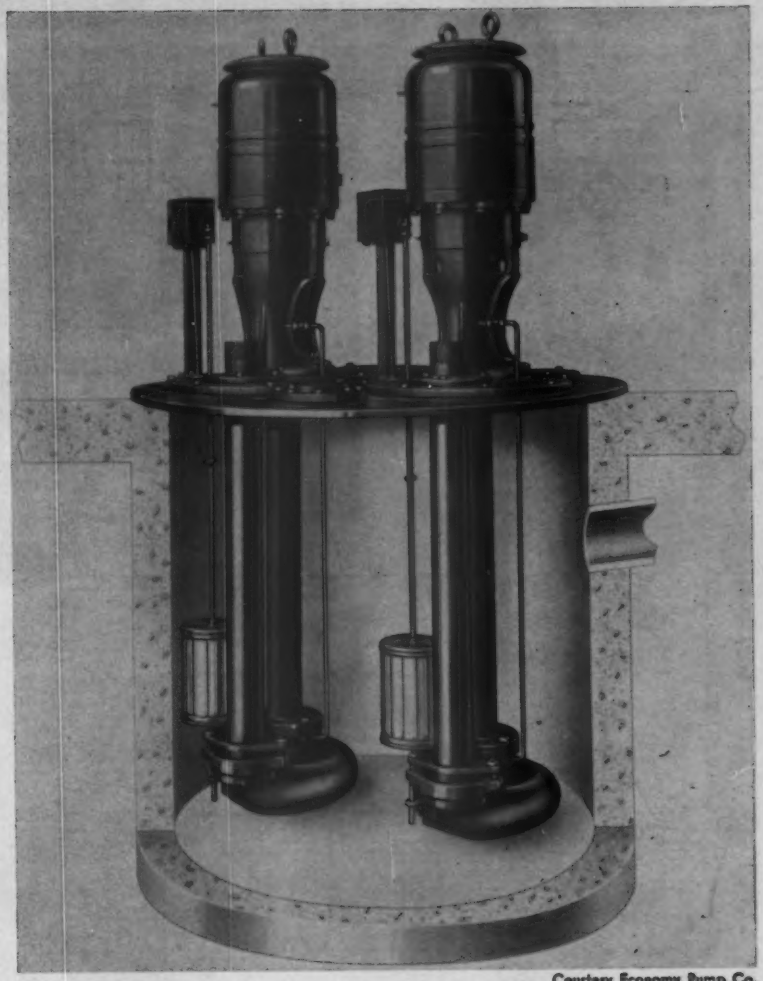
Sump Pumps

The term "sump" pump generally conveys the idea of a vertical wet-pit pump suspended from a floor plate or sump cover, or supported by a foot on the bottom of a well, usually motor-driven and automatically controlled by a float switch, to remove drainage collected in a sump. The term does not indicate any specific type of construction, as both diffuser and volute type, single- or multi-stage, with open and closed impellers of a wide range in specific speed type, have been employed for this service.

For the very small capacity field, where fractional horsepower motors can be used, "cellar drainers" can be obtained. These are small, usually single-stage volute pumps, with single-suction impellers, either bottom or top suction, supported by a foot on the casing, with the motor supported some distance above by some form of column enclosing the shaft. Such cellar drainers are made as complete units, with float, float switch, motor and strainers completely assembled as a unit (Fig. 2).

Larger capacity sump pumps may be of the vertical propeller or turbine pump type (single- or multi-stage), or of the vertical wet-pit sewage or volute type. Where solids or other waste materials may be washed into the sump, the vertical wet-pit sewage pump with a non-clogging type of impeller is preferred for such sump pump service.

The larger capacity sump pumps are usually more or less standard de-



Courtesy Economy Pump Co.

FIG. 3. TYPICAL duplex sump pump.

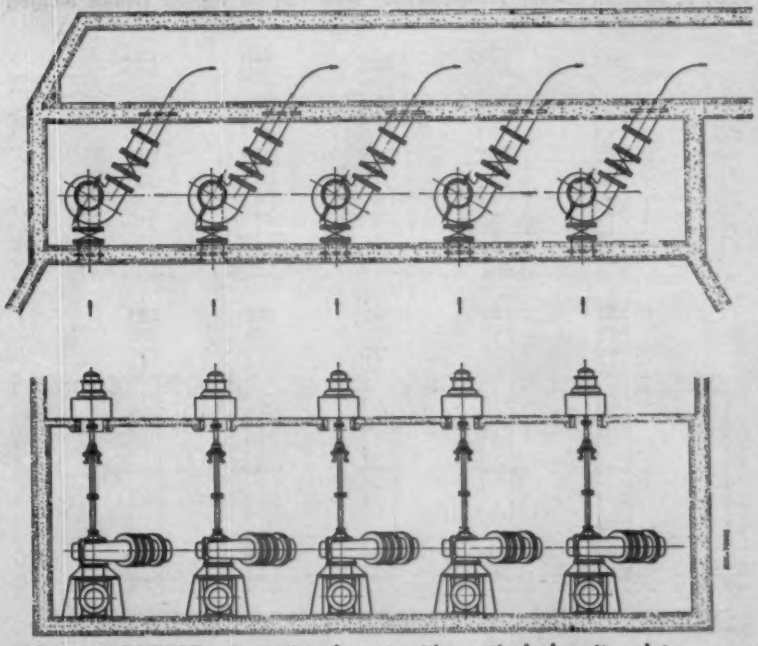


FIG. 4. MULTIPLE-unit station layout with vertical dry-pit volute pumps installed lengthwise along a long suction bay.

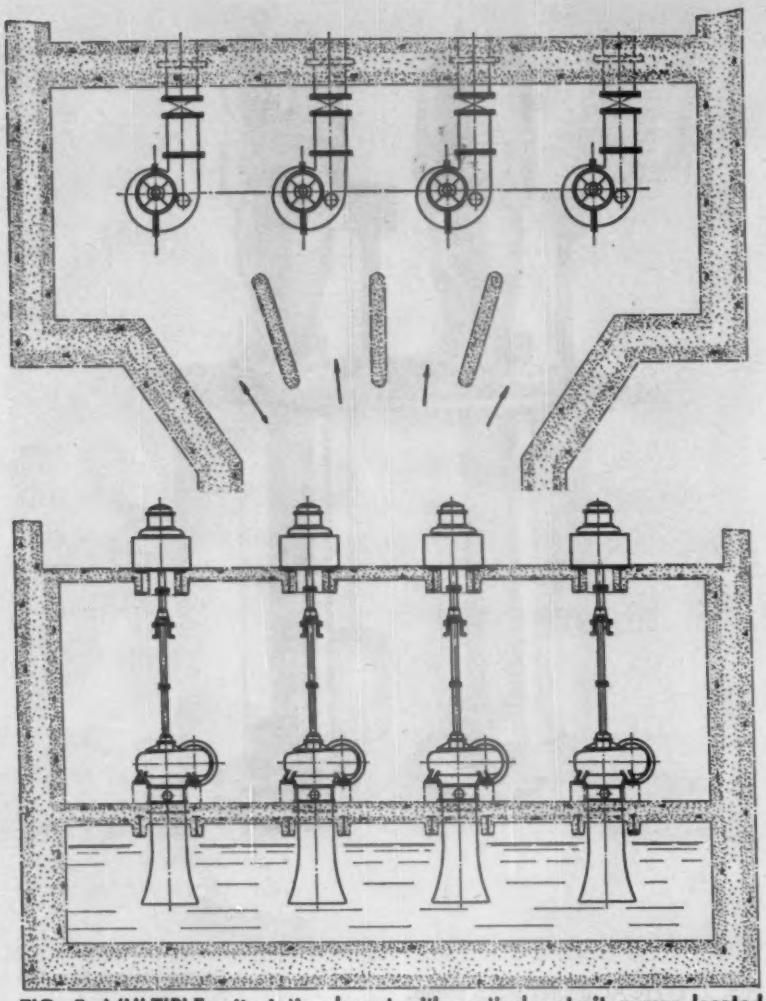


FIG. 5. MULTIPLE-unit station layout with vertical wet-pit pumps located at the end of a conduit.

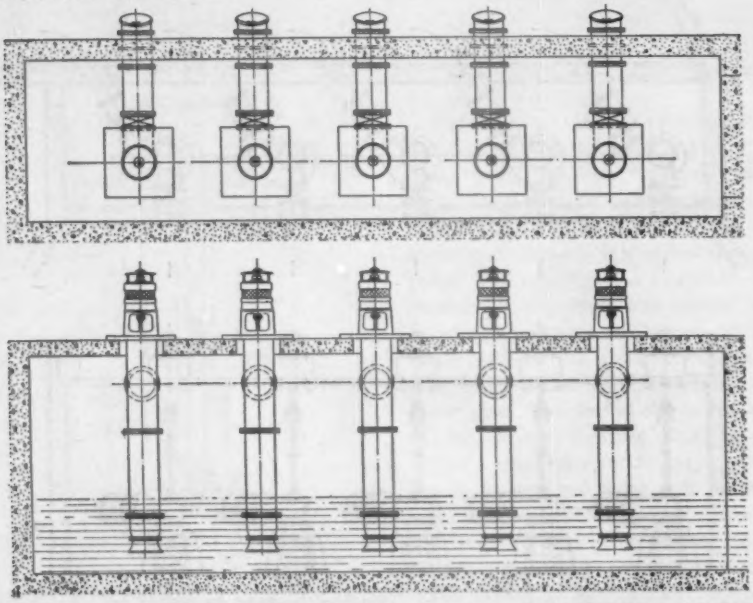


FIG. 6. MULTIPLE-unit station layout of vertical propeller pumps with the suction supply from one end of the well can cause difficulties.

signs, but obtainable in any length, with various size sump covers, float switch mounted on the sump cover, etc. Often duplex units (that is, two pumps on a common sump cover, possibly with a manhole for access to the sump) are used (Fig. 3). Such duplex units may have the pumps operate in a fixed order, or a mechanical or electrical alternator can be used to equalize the operation of the two pumps.

Application of Vertical Wet-Pit Pumps

Like all other pumps, the vertical wet-pit type has advantages and disadvantages, the former being mostly hydraulic and the latter mechanical. With the impeller (or first-stage impeller in case of multi-stage pumps) submerged, there is no priming problem, and the pump can be automatically controlled, with no concern that the unit will ever run dry. Also being submerged, the net positive suction head, in cases other than a closed tank, is greater, often permitting a higher rotating speed for the same service conditions. The only mechanical advantage is that the motor or drier can be located at any desired height above any floor level. The mechanical disadvantages are: possibility of freezing when idle; possibility of damage by floating objects if installed in an open ditch or similar installation; inconvenience of pulling and dismantling for inspection and repairs, no matter how small; and, finally, relatively short life of the pump bearings unless the water conditions and bearing design are ideal. The vertical wet-pit pump is the best for some applications; not ideal, but most economical for other installations; a poor choice for others; and least desirable for still other cases.

Typical Arrangements of Vertical Pumps

A pump is only part of a pumping system. The hydraulic design of the system external to the pump will be reflected in the over-all economy of the installation. Only too easily can the design of the installation have an adverse effect on the performance of the pump or pumps. This is particularly true in the case of vertical pumps, because the small floor space occupied by each unit offers the temp-

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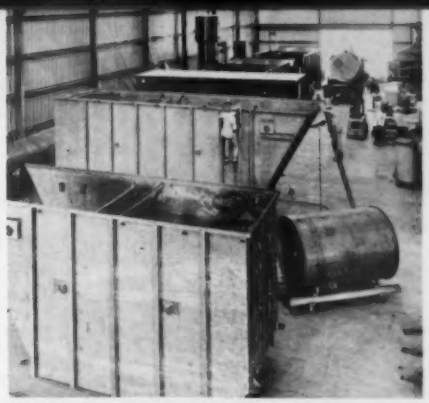

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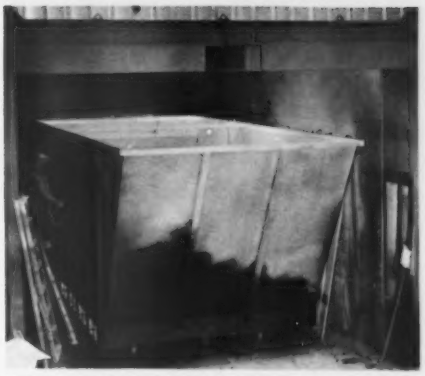


EPOXY RESIN COATINGS have proved their merit in underground installations of steel structures. Smith & Loveless pioneered the use of epoxy in the lift station field, offering the most tenacious, corrosion-resistant protective coating ever developed. New, undiluted "Versapox" in a one-coat application of 100% reactive resin is standard on all Smith & Loveless factory-built products—the highest standard in the industry.

SKILLED ELECTRICAL TECHNICIANS build the control system for each specific job. In this modern electrical shop, every control panel is expertly wired, assembled, examined and tested to assure trouble-free operation in the field.

COMPLETE STATION TESTING is a "must" requirement for every Smith & Loveless product. Before shipment, each lift station is tested under simulated field conditions for several hours . . . your assurance of receiving a trouble-free thoroughly tested station.

ON-THE-SITE DELIVERY by special Smith & Loveless trucks—or by rail, in the case of larger units—means "no delay" at installation time. The lift station or treatment plant arrives ready for installation, quickly and economically, in as little as one day.

FACTORY-BUILT SEWAGE PUMP STATIONS

HERE'S HOW THEY OPERATE: Beside the sewage pump station is a wet well or receiving manhole that receives the inflowing sewage. As the wet well level rises, the pipe ① of the air-bubbler system is submerged in the sewage, causing an increasing back pressure on the steady stream of air that is being ejected into the wet well by the compressor in the control panel ②. At a predetermined level, this back pressure in the system actuates a mercury pressure switch which energizes a magnetic starter. One of the pumps ③ goes on and the sewage flows out of the wet well, into the station, through the inlet pipe ④, through a gate valve ⑤, into the pump ⑥, out through a check valve ⑦, the discharge gate valve ⑧ and out the discharge force main ⑨.

The sensitive mercury pressure switches for each of the sewage pumps are set at different levels so when necessary all pumps will operate to handle maximum flows. An automatic alternator is provided to change the sequence of operation of the pumps on the completion of each pumping cycle. This allows even distribution of the work load on the pumps. It, too, provides for all pumps to operate simultaneously should the level of the wet well continue to rise above the starting level for the low-level pump cycle.

The system is automatic, efficient and dependable.

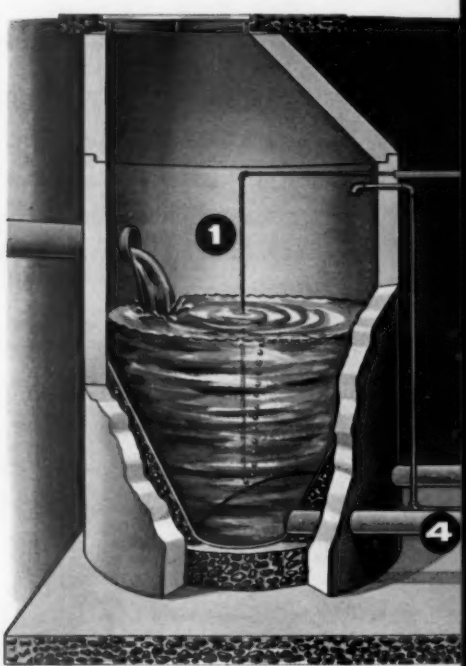
Complete specifications, job recommendations, installation instructions, detailed drawings, pump-selection charts, operating instructions and a representative list of installations can be found in the 100-page data manual on Smith & Loveless sewage lift stations.

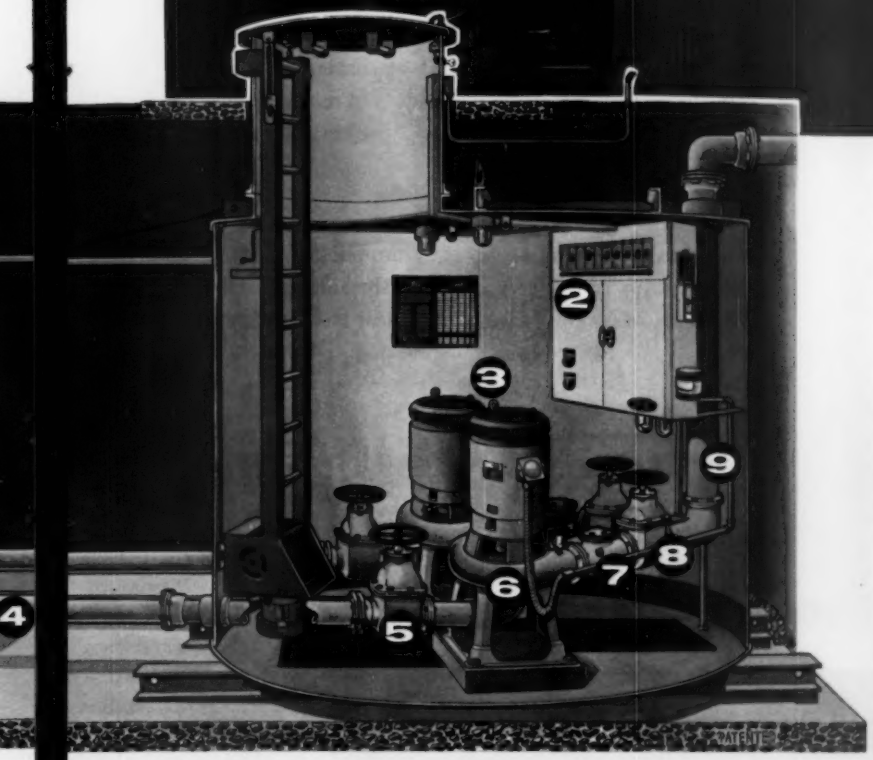
SEE BULLETIN 601

A 16 mm, color-sound motion picture on factory-built sewage lift stations by Smith & Loveless is available through sales representatives in principal cities.

Smith & Loveless Factory-Built Sewage Pumping Stations are built to provide a lifetime of dependable service—available for capacities from 100 to 4,500 GPM per pump with two, three and four pumps per station with a wide variety of control systems including variable speed controls and flow-matching systems, ozone generators, elevators, and alarm systems. Even larger capacity stations are built to order.

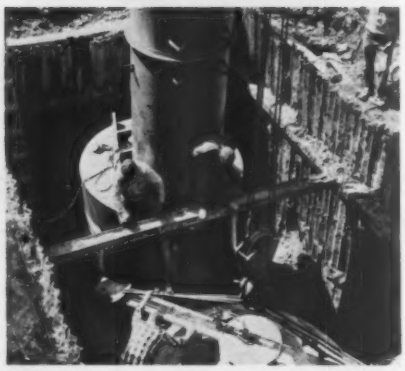
The Smith & Loveless sewage pump station is a complete factory-built unit that includes all equipment ready to operate. Every item of mechanical and electrical equipment has been factory-tested by actual operation under simulated design conditions to assure proper operation in the field.





The interior of the Smith & Loveless pump station is attractive, efficiently designed and clean, with conditioned air. The station is compact, yet all equipment is readily accessible to the operator.

Only the entrance tube of the factory-built pump station is visible above ground, making it inconspicuous, quiet and vandal-proof.



Install in Less Than a Day...

Through proper production timing and coordination with the installing contractor, the Smith & Loveless sewage pump station can be scheduled for delivery to the installation site on time, when needed by the contractor, with all mechanical equipment ready to operate. The pump station is delivered to the job site on special-made trucks—or by rail in the case of larger units. It can be installed in less than a day—and complete installation and operating instructions are delivered with the pump station.

The wet well, beside the sewage pump station, may be constructed before the station is delivered or during installation, as at left. After installation of the suction lines, force main, and the electrical connections are made, the excavation is backfilled.

Featuring... the Smith & Loveless Vertical Close-Coupled "Non-Clog" Sewage Pump with double mechanical seal that eliminates expensive replacement of worn-out shaft sleeves, and the leakage and maintenance problems of old-fashioned pump packing.

When inevitable wear makes it necessary to replace the dead-tight seal, it can be done by one man in less than 30 minutes—a far cry from packing or seal maintenance on other pumps on the market. Designed for easy maintenance and built to close tolerances . . . heavy, rugged construction.

SEE BULLETIN 500

Built to the Most Exacting Requirements by the World's Largest Manufacturer of Factory-Built Sewage Lift Stations.

Smith & Loveless

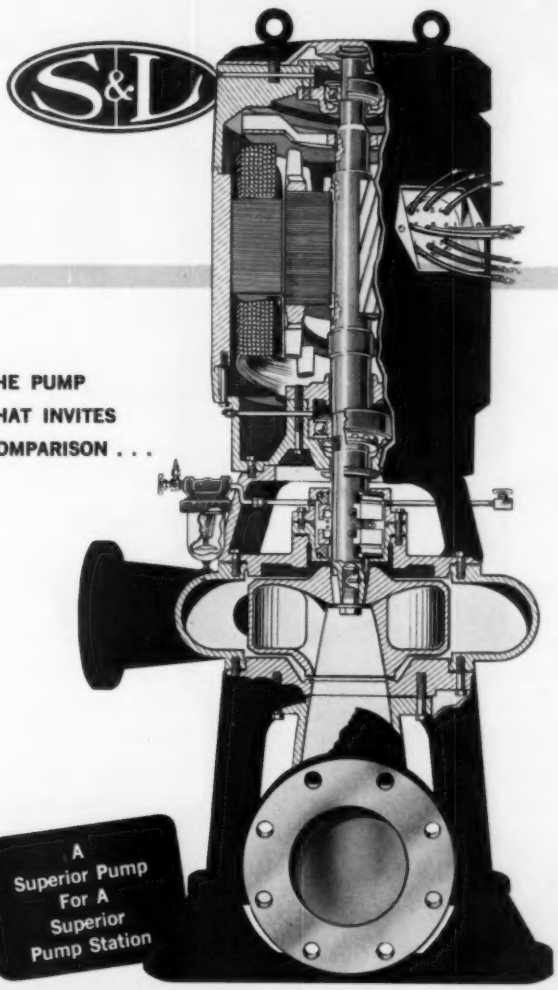
THE ONE PUMP DESIGNED TO MEET *All* OF

Built for Easy Maintenance...

Smith & Loveless Sewage Pump Stations are built "with the maintenance man in mind." Cover rungs extend the ladder for his safe entry, and when he lifts the cover, the lights and ventilating blower turn on, automatically.

His station comes complete with understandable maintenance and operating instructions, full color-coded wiring in the control panel, easy-to-reach starter and breaker switches, all fully identified for his convenience and safety—a dependable, patented ventilating system and humidity control—plus ample "elbow room" so he can work more efficiently.

Every detail designed to make his job easier, faster, safer.



THE PUMP THAT INVITES COMPARISON . . .

A Superior Pump For A Superior Pump Station

THE MUST REQUIREMENTS FOR SEWAGE SERVICE.

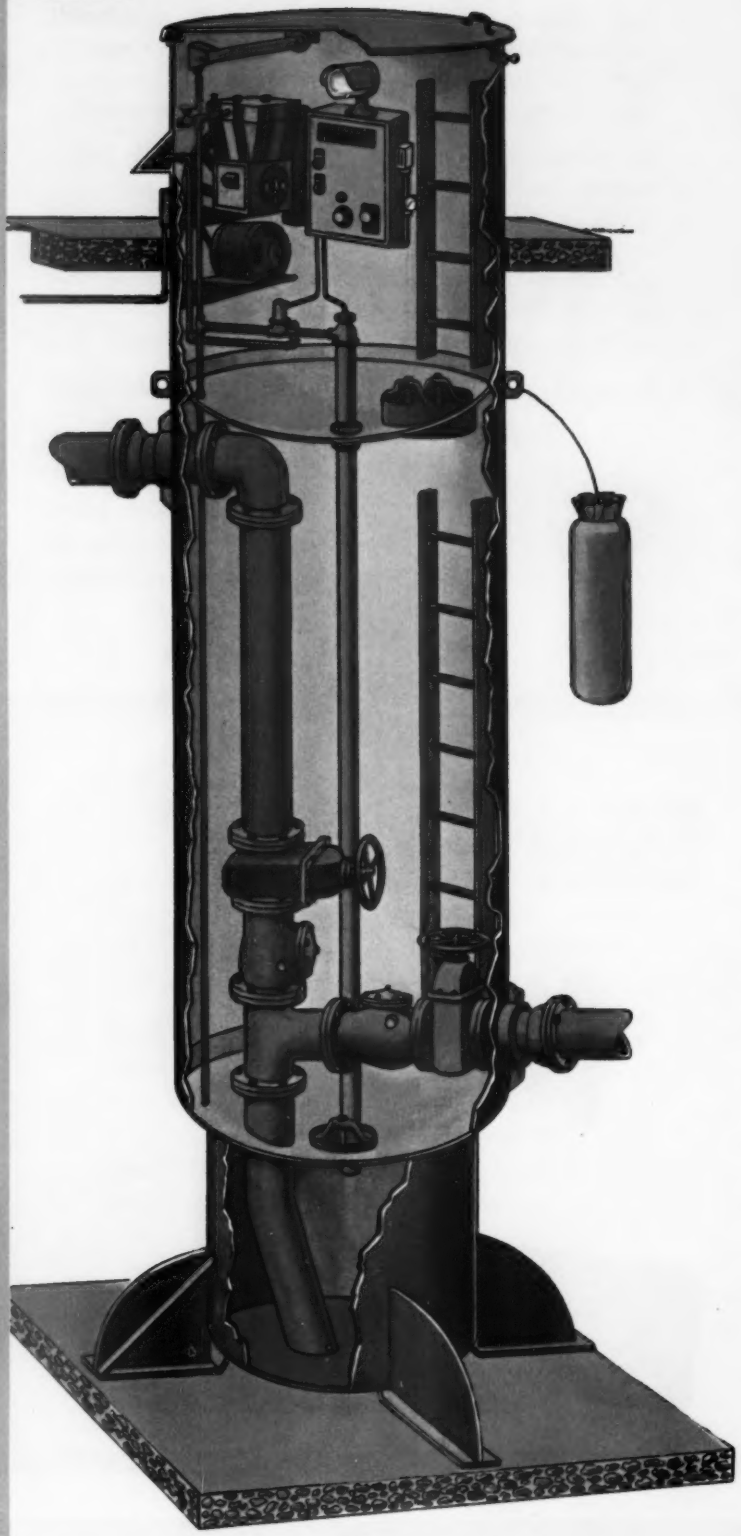
"MON-O-JECT"®

The Smith & Loveless "Mon-O-Ject" simplex pneumatic ejector lift station is a cylindrical steel chamber with three individual compartments. The top compartment is easily accessible from ground level and houses the ejector controls and compressor. The middle section is a combination air-storage tank and chamber for the valves and manifold. The bottom compartment is the sewage receiver.

The pneumatic ejector lift station is recommended where the rated capacity is less than 100 GPM. A four-inch centrifugal pump, designed for three-inch solids, is the smallest which will operate with reasonable freedom from clogging on raw sanitary sewage. Such a pump is not available with a rated capacity less than 100 GPM. Therefore, to lift smaller flows, the pneumatic ejector is the only satisfactory answer. Only the larger sewage pumps can match the pneumatic ejector in its ability to handle large sewage solids.

SEE BULLETIN 615

TYPICAL INSTALLATION of a Smith & Loveless "Mon-O-Ject" sewage lift station serving a school in the suburbs of a growing community.



IDEAL FOR SMALL SUBDIVISIONS
MOTELS • SCHOOLS • FACTORIES • TRAILER PARKS

"DU-O-JECT"®

The Smith & Loveless "Du-O-Ject" duplex pneumatic ejector lift station is the equivalent to two "Mon-O-Ject" stations, combined into the same structure with dual piping and receivers. The "Du-O-Ject" provides the added dependability of complete stand-by equipment throughout and extra capacity for peak loads.

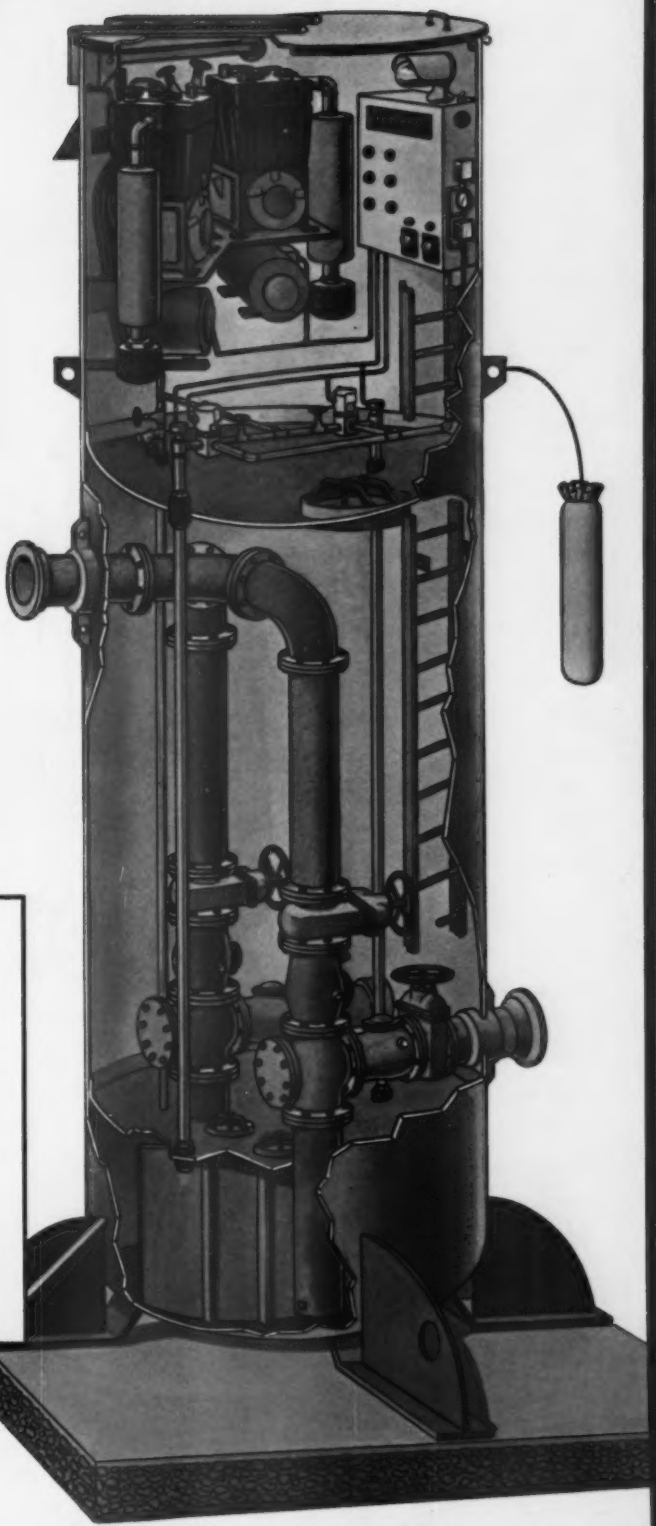
The "Du-O-Ject" is a cylindrical steel chamber with three individual compartments, housing the controls, the valves and the sewage receivers. The top compartment is easily accessible from ground level and houses the ejector controls and compressors. The middle section is a combination air-storage tank and chamber for the dual piping, valves and common discharge piping into the force main. The bottom section is divided into two separate compartments which are the sewage receivers.

SEE BULLETIN 616

Both Equipped with Exclusive "No-Fail" Electrode System

An exclusive "No-Fail" Electrode System (Patents Pending)—composed of heavy-duty rectifiers and capacitors, ultra-sensitive DC relays, high-accuracy timing units and a uniquely designed, hollow electrode—prevents grounding and insulation failures that put conventional ejectors out of operation. The "No-Fail" system makes these units the most trouble-free sewage ejectors on the market today.

Complete specifications and information on the "No-Fail" Electrode System can be obtained by writing for the 100-page data manual on Smith & Loveless sewage lift stations.

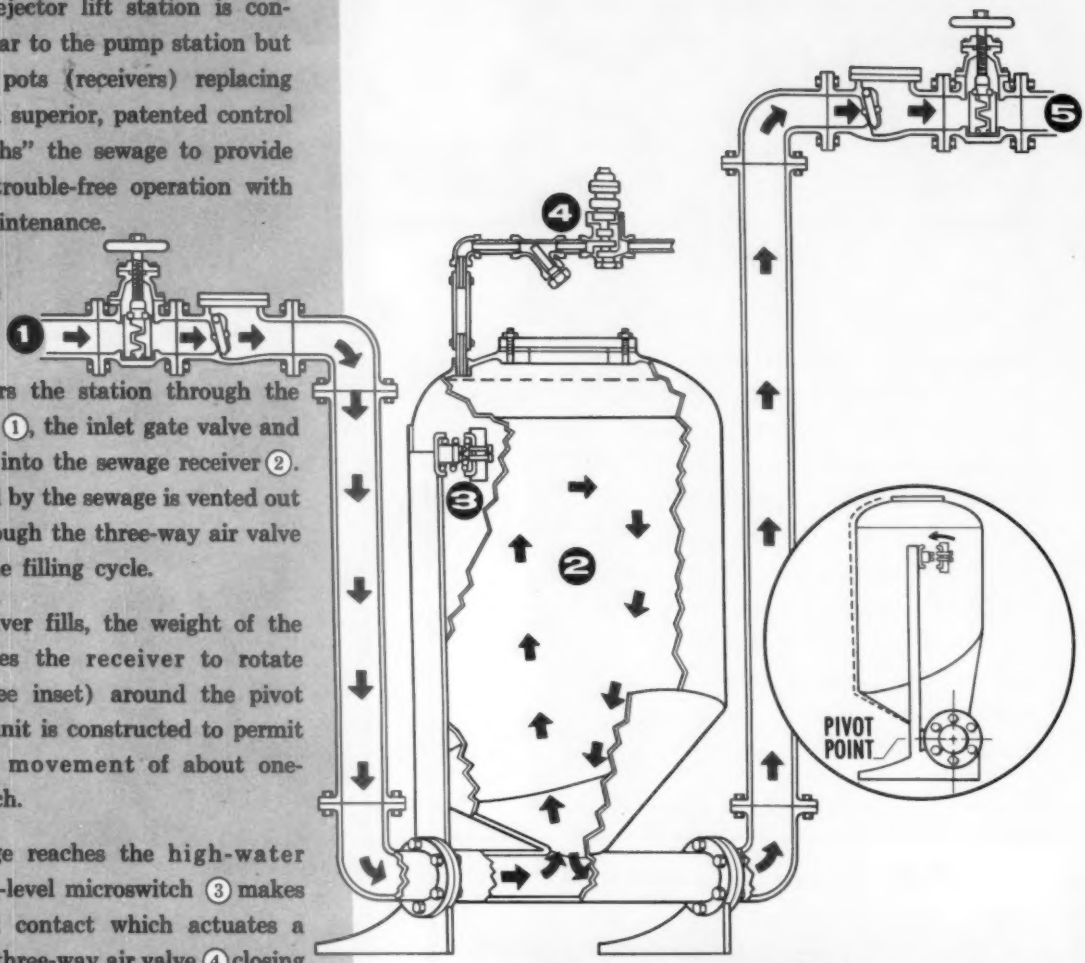


DESIGNED FOR LOW CAPACITIES:
FROM 30 TO 200 GALLONS PER MINUTE

"WAY-O-MATIC"®

The Smith & Loveless "Way-O-Matic" pneumatic ejector lift station is constructed similar to the pump station but with ejector pots (receivers) replacing the pumps. A superior, patented control system "weighs" the sewage to provide dependable, trouble-free operation with minimum maintenance.

SEE BULLETIN 410



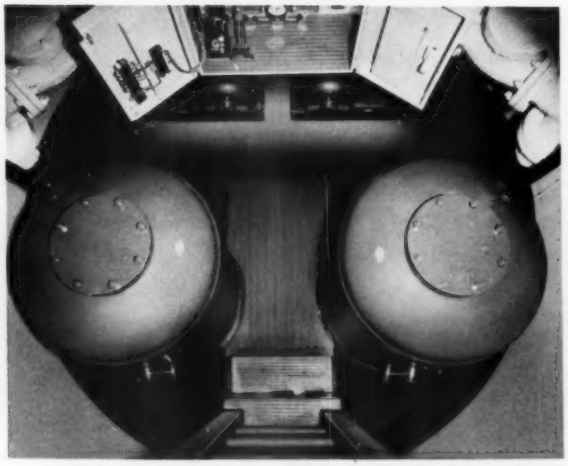
Sewage enters the station through the influent pipe (1), the inlet gate valve and check valve, into the sewage receiver (2). Air displaced by the sewage is vented out of doors through the three-way air valve (4) during the filling cycle.

As the receiver fills, the weight of the sewage causes the receiver to rotate slightly (see inset) around the pivot point. The unit is constructed to permit a maximum movement of about one-sixteenth inch.

When sewage reaches the high-water level, a high-level microswitch (3) makes an electrical contact which actuates a relay to the three-way air valve (4) closing off the vent line and opening the connection to the compressed air supply. The compressed air forces the sewage out the discharge manifold through the discharge check valve, gate valve and into the force main. (5).

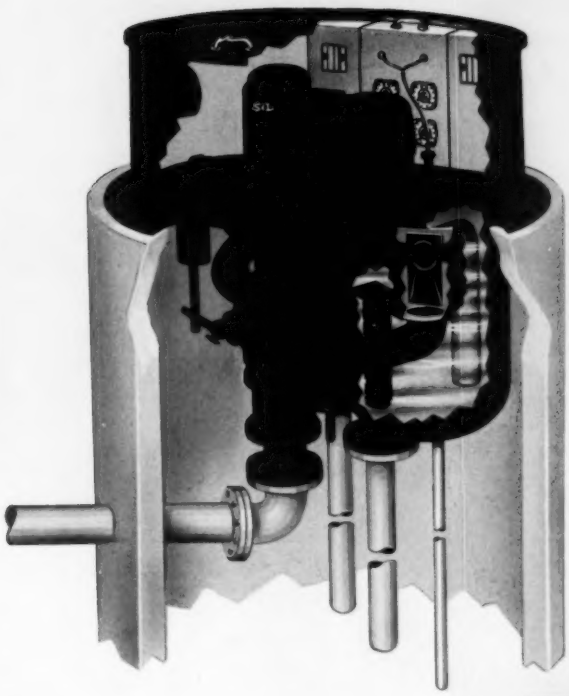
As the sewage level falls, the receiver pivots back into the empty position, breaking the electrical contact and de-energizing the three-way air valve which cuts off the air supply and reconnects the vent line.

DESIGNED FOR LOW CAPACITIES FROM 30 TO 200 GALLONS PER MINUTE



This interior view of the Smith & Loveless "Way-O-Matic" shows the arrangement of the ejector pots, control panel and compressors.

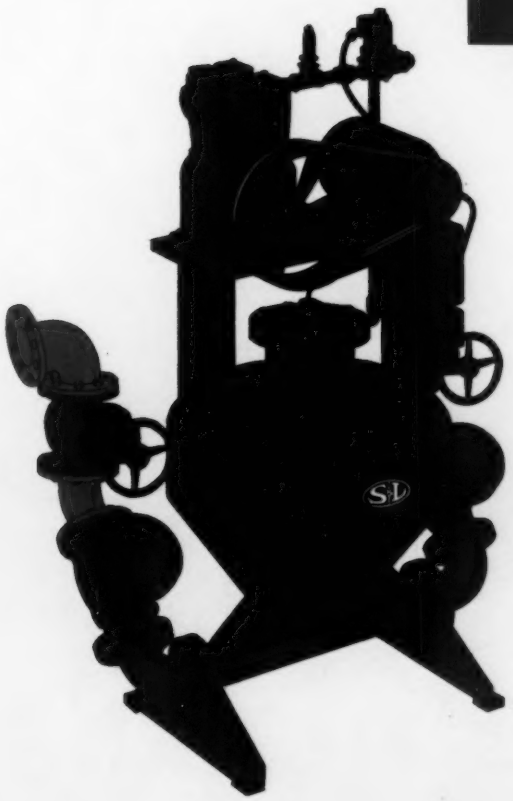
"VAC-O-JECT"®



The Smith & Loveless "Vac-O-Ject" pneumatic ejector provides two-stage lifting action and is designed for installation on a standard four-foot wet well or receiving manhole. It incorporates the principle of vacuum intake and air-pressure ejection and is equipped with the exclusive Smith & Loveless "No-Fail" Electrode System.

As sewage rises in the wet well, an electrode starts a reversible air pump which evacuates air from the receiver. Atmospheric pressure forces sewage up to the receiver. When filled, an electrode stops the air pump, reverses it and ejects the sewage.

"PRES-O-JECT"®



The Smith & Loveless "Pres-O-Ject" is a compact, factory-built pneumatic ejector. It can be specified with the conventional electrode system or the exclusive Smith & Loveless "No-Fail" Electrode System.

Sewage flows by gravity into the sewage receiver. When filled, an electrode actuates a Solenoid valve which closes off the vent line and starts the air compressor which forces air into the sewage receiver, ejecting the sewage.

Designed for capacities from 30 to 200 G.P.M., the "Pres-O-Ject" can be installed in simplex or duplex arrangements.

FACTORY-BUILT SEWAGE TREATMENT PLANTS

Smith & Loveless
"OXIGEST"®

The factory-built "Oxigest" sewage treatment plant is designed specifically for small subdivisions, mobile home courts, motels, shopping centers, resorts, hospitals, schools, factories and apartments in outlying areas without municipal sewerage facilities.

Available in a variety of standard sizes, "Oxigest" units can be installed in parallel, either simultaneously to provide a plant of greater capacity than is possible with a single unit, or at intervals after the initial unit is placed in operation to keep pace with a growing sewage load from an expanding subdivision, school or other development.

The treatment plant can be transferred from one location to another as the expansion of municipal sewerage systems eliminate the need for private or independent sewage facilities.

For information on how this "Aerobic Digestion" treatment plant operates, complete specifications, data and drawings, write for the 100-page data manual on Smith & Loveless sewage treatment plants.

SEE BULLETIN 1200

A 16 mm, color-sound motion picture on Smith & Loveless factory-built sewage treatment plants, starring Mike Microbe, is available through sales representatives in principal cities.

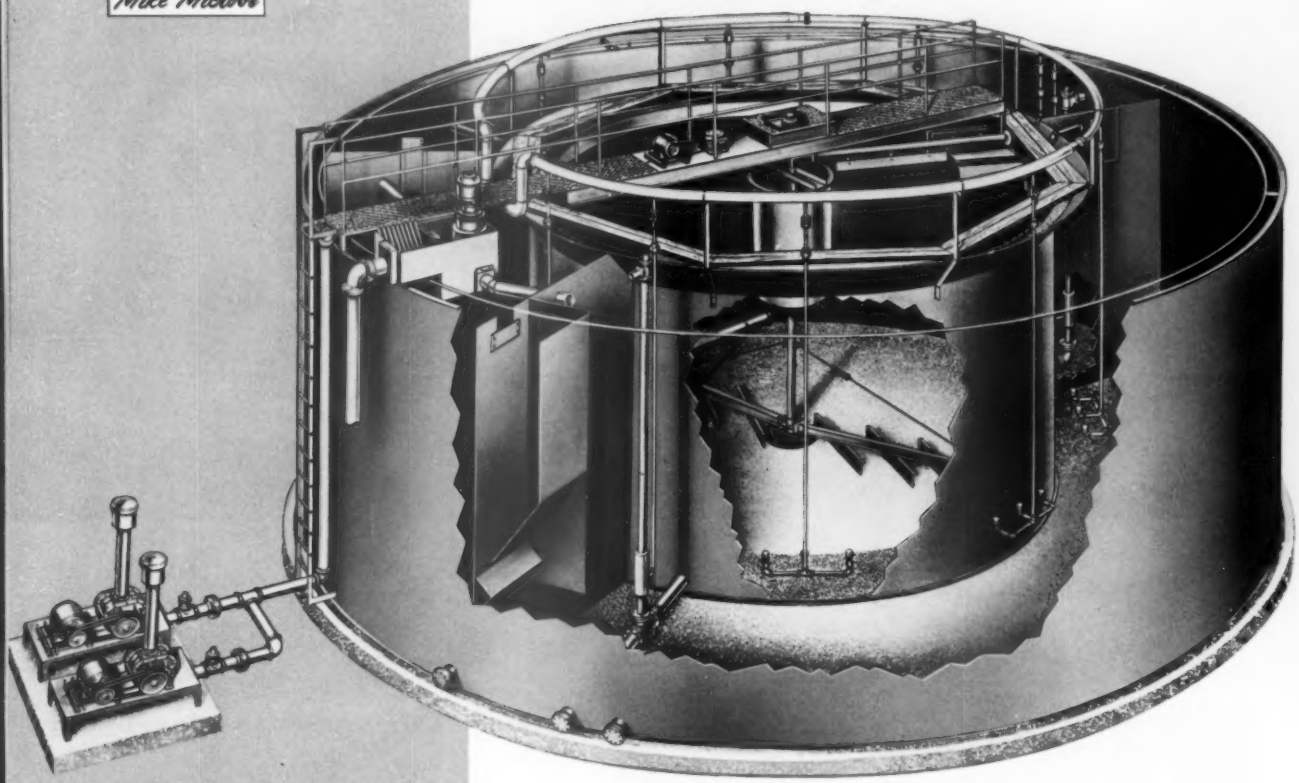
Dependable Sewage Treatment FOR MOTELS, MOBILE HOME PARKS, SMALL SUBDIVISIONS, FACTORIES, SCHOOLS, MILITARY BASES

FIELD-ERECTED SEWAGE TREATMENT PLANT

Smith & Loveless

"OXIGEST®"

For installations with capacities from 30,000 to 500,000 gallons per day to serve 300 to 5,000 persons, Smith & Loveless offers the factory-fabricated, field-erected "Oxigest" sewage treatment plant.



SEE BULLETIN 1220

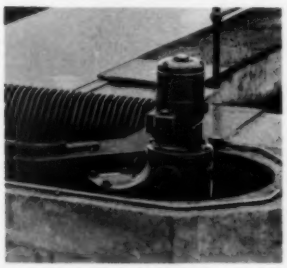
The field-erected "Oxigest" provides dependable sewage treatment with minimum maintenance. It is designed for small communities, large, growing subdivisions, military bases, resorts and industrial developments in outlying areas not served by municipal sewerage systems. Available in 17 sizes to meet a wide range of applications.

Designed for Larger Capacities TO SERVE SMALL COMMUNITIES, GROWING SUBDIVISIONS.

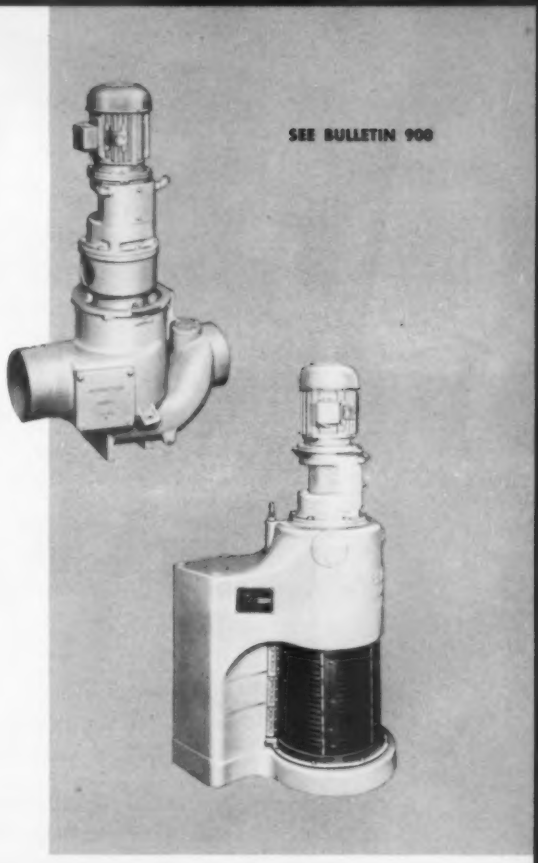
COMMINUTORS

Smith & Loveless offers a complete line of high-quality comminutors, engineered to provide continuous, automatic screening and cutting of large sewage solids into small particles without removing the solids from the sewage flow.

The comminutor is ideal for location at a sewage treatment plant, at sewage outfalls or for special applications at factories or commercial establishments—where ever large sewage solids must be screened, shredded or cut up. Smith & Loveless' complete line of comminutors are backed by more than 20 years' experience and proved by installations all over the world.



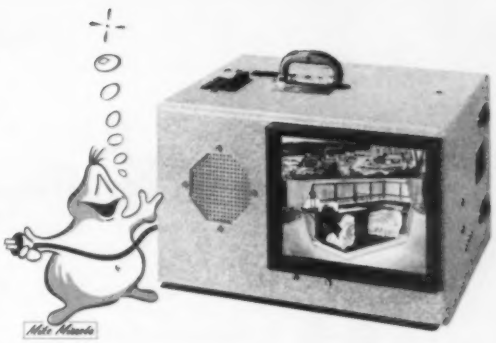
For information on the quality comminutors offered by Smith & Loveless, write for the 100-page data manual on sewage treatment plants.



MOTION PICTURES Tell the S+L Story

Smith & Loveless 16 mm, color-sound industrial movies on factory-built sewage lift stations and "Oxigest" sewage treatment plants are available through sales representatives all over the United States, Canada and Europe.

Operational characteristics are explained by complete animated sequences. The movies show the design features, manufacture and installation of Smith & Loveless sewage pump stations and sewage treatment plants.



Available for viewing at meetings and conferences, or in your own office via a unique portable projector.

WRITE for free engineering data manuals on Smith & Loveless Sewage Lift Stations and "Oxigest" Sewage Treatment Plants.

The manual on factory-built sewage lift stations includes complete installation and operation data, selection and capacity charts, sample specifications and performance material on Smith and Loveless' complete line of pumping stations, sewage pumps and pneumatic ejectors.

The data manual on factory-built and field-erected "Oxigest" Sewage Treatment Plants features notes on treatment processes, plant design, operational characteristics, dimension drawings, shipping weights, installation data, accessory equipment and sample specifications.

Ask For The Name of Our Representative in Your Area

WRITE DEPARTMENT 2040D

Smith & Loveless

ONE OF THE UNION TANK CAR COMPANIES

P. O. BOX 8884

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PLANT: LENEXA, KANSAS

IN CANADA: SMITH & LOVELESS COMPANY, DIVISION-PRODUCTS TANK LINE OF CANADA
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tation to reduce the size of the station by placing the units closer together. In such cases the suction arrangement may not permit the proper flow of water to the pump suction intake. Many factors are involved in the design of a suction well and the location of a bellmouth. No simple rules or relations can be applied with complete assurance; therefore, none are included in this discussion. The physical size of the pumps, whether of the propeller or volute type, rarely affects the design of the suction well, the location of the bellmouth, or the spacing of the units. These are usually controlled by the factors governing the proper flow of the water to the bellmouth.

Fig. 4 illustrates an ideal arrangement for a multiple-unit station with dry-pit pumps. It provides an unrestricted flow on the suction side of all the units. Often, stations using this arrangement for a group of vertical volute pumps have the suction bellmouths and elbows formed right in the concrete substructure.

When wet-pit pumps are installed with vertical bellmouths, adequate clearance must be provided from the back wall and between the units, as in Fig. 5, which illustrates a common situation in which the suction is located at the end of a conduit whose width is less than the length of the suction well. Without a flared section with division walls to guide the distribution of the incoming water to the various units, the flow would be badly distributed and the operation of the pumps affected unfavorably.

An arrangement which is often troublesome with propeller pumps (and with vertical volute pumps provided with suction bellmouths as in Fig. 5) is shown on Fig. 6. Unless the width of the suction well gives sufficient area and unless the locations of the bellmouths permit good flow, the demand of the units first in line will disturb the flow of the units further from the supply conduit. Installations of this general arrangement often require extensive baffling to correct the distribution to the various units. To overcome the problem of such a layout, some stations are made with walls forming individual wells for each pump, with a channel to supply them running lengthwise of the station. Certain recommendations have been developed over the years for the dimensioning of intake channels and approaches. Wherever possible, an intake as illustrated in Fig. 7 will give excellent results. The dimensions of channel width and spacing are given in terms of the suction bellmouth diameter. An example of good channel and pit design for vertical turbine pumps is also given in Fig. 8. It will be noted that

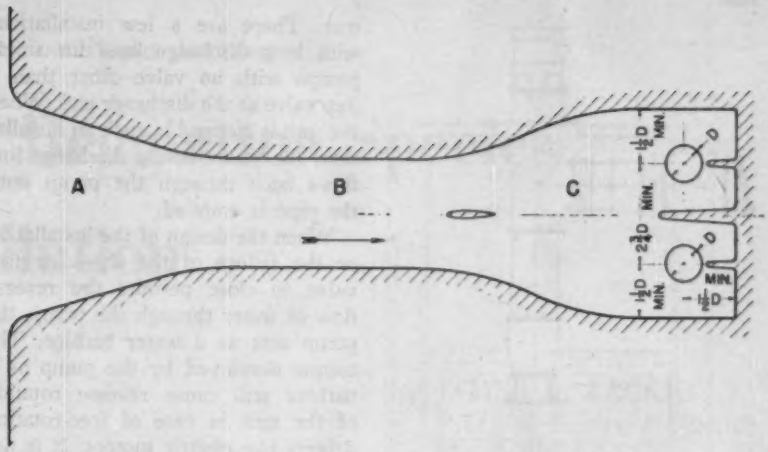

FIG. 7. TYPICAL pump installation with a good intake design.

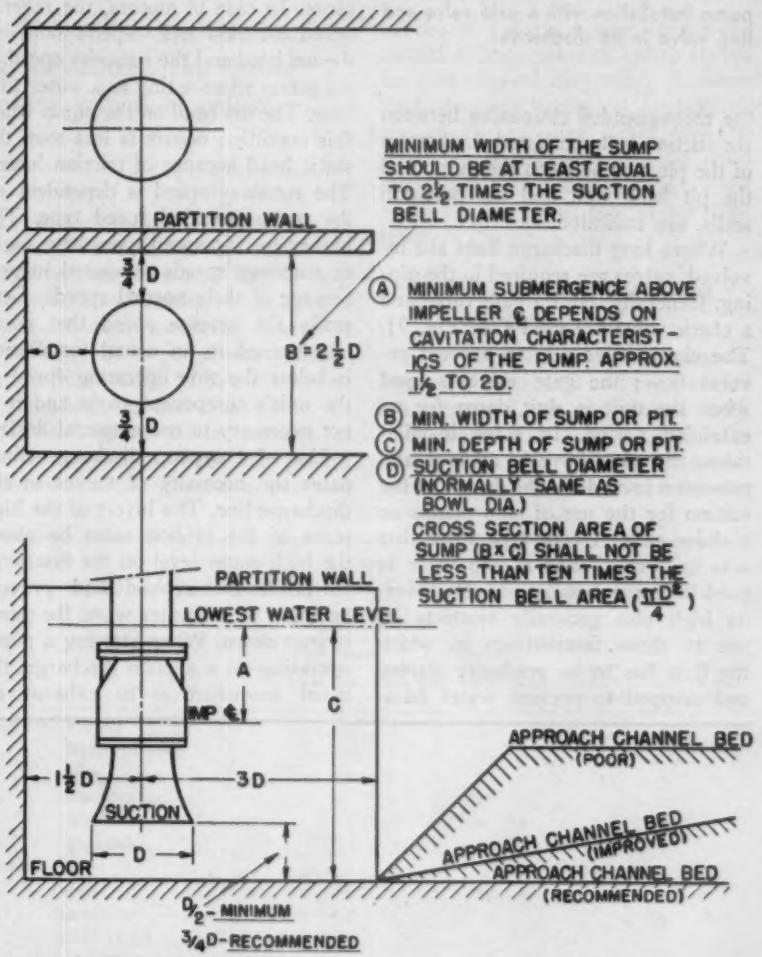
MINIMUM WIDTH OF THE SUMP SHOULD BE AT LEAST EQUAL TO 2½ TIMES THE SUCTION BELL DIAMETER.
PARTITION WALL
¾ D
D
B = 2½ D
¾ D
(A) MINIMUM SUBMERGENCE ABOVE IMPELLER ℄ DEPENDS ON CAVITATION CHARACTERISTICS OF THE PUMP. APPROX. 1½ TO 2D.
(B) MIN. WIDTH OF SUMP OR PIT.
(C) MIN. DEPTH OF SUMP OR PIT.
(D) SUCTION BELL DIAMETER (NORMALLY SAME AS BOWL DIA.)
CROSS SECTION AREA OF SUMP (B x C) SHALL NOT BE LESS THAN TEN TIMES THE SUCTION BELL AREA ($\frac{\pi D^2}{4}$)
PARTITION WALL
LOWEST WATER LEVEL
A
IMP ℄
C
APPROACH CHANNEL BED (POOR)
1½ D
3D
SUCTION
D
APPROACH CHANNEL BED (IMPROVED)
FLOOR
APPROACH CHANNEL BED (RECOMMENDED)
D/2 - MINIMUM
¾D - RECOMMENDED

FIG. 8. RECOMMENDED dimensions of channel and pit design for vertical turbine pumps.

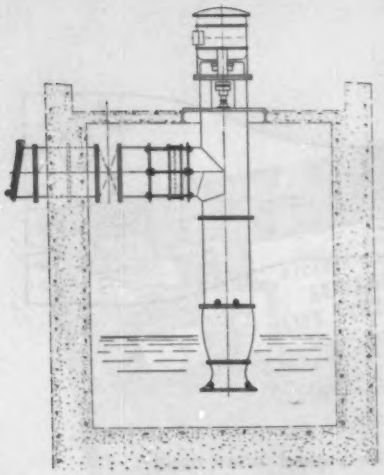

FIG. 9. VERTICAL wet-pit propeller pump installation with a gate valve and flap valve in its discharge.

the recommended clearances between the suction bellmouth and the bottom of the pit, and between the pump and the pit back wall and the partition walls, are indicated.

Where long discharge lines are involved, valves are required in the piping. Generally, both a gate valve and a check valve are used (see Fig. 9). The check valve acts to prevent reverse flow; the gate valve is used when the unit is shut down for an extended period. In some installations, the gate valve is omitted and provision is made in the design of the station for the use of stop planks or a sluice gate. A cone-type valve that acts as a check and a stop valve is used for some installations. However, its high cost generally restricts its use to those installations in which the flow has to be gradually started and stopped to prevent water hammer. There are a few installations with long discharge lines for single pumps with no valve other than a flap valve at the discharge end. When the unit is stopped in such an installation, the water in the discharge line flows back through the pump until the pipe is emptied.

When the design of the installation or the failure of the check or flap valve to close permits the reverse flow of water through the pump, the pump acts as a water turbine. The torque developed by the pump as a turbine will cause reverse rotation of the unit in case of free-rotating drivers like electric motors. It is not generally sufficient to cause reverse rotation for internal combustion engines. In case of motors, the reverse speed attained will depend both on the net head and the runaway speed of the pump when acting as a water turbine. The net head on the pump when this condition occurs is less than the static head because of friction losses. The runaway speed is dependent on the pump specified speed type. The higher specific speed types have higher runaway speeds measured in percentage of their normal speeds. Generally the reverse speed that could be obtained in an actual installation is below the safe operating speed of the unit's component parts and it is not necessary to use a special design.

Use of a syphon discharge eliminates the necessity of valves in the discharge line. The invert of the high point of the syphon must be above the high-water level on the discharge to break the syphon and prevent backflow of the water when the pump is shut down. When starting a pump operating on a syphon discharge, the usual procedure is to exhaust air

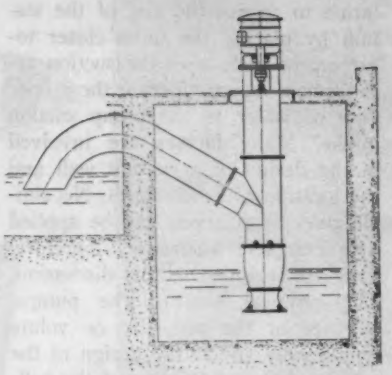

FIG. 10. VERTICAL wet-pit propeller pump installation with syphon discharge.

from the system by some priming device until the pump is primed. The pump may then be started to aid in filling the syphon. The connection to the high point of the syphon is also provided with a valved opening so air can be admitted and the syphon broken when it is desired to stop the unit. It is possible to have this admission of air automatically controlled so that it functions if the unit stops for any reason.

Although syphons with short legs are relatively simple and little trouble is experienced in their design or operation, more care must be taken as the syphon leg is lengthened. Although there are successfully operating syphons with legs over 25 feet in length, they are primarily limited to power plant installations on circulating water systems. A syphon discharge is desirable in drainage installations pumping over a levee and results in a lower head than would be obtained if the water were discharged at the top of the levee.

Growth in many areas under various conditions describes . . .

Occurrence of Beggiattoa Species Relative to Pollution

by JAMES B. LACKEY
Prof. of Sanitary Science
University of Florida
Gainesville, Florida

EDITOR'S NOTE: In the continuing studies of biota as indicators of water resource pollution, an occasional blank is drawn. Professor Lackey and his associates conclude that the Beggiatoa are not responsive to environmental pollutional changes. This finding is a significant contribution to the growing volume of pollution control references.

■ Reference is often made to the cosmopolitan distribution of organisms. In a sense this is true, but it actually means the occurrence of certain environmental conditions within the range of tolerance of a given organism, in different parts of the world. If an organism tolerates only a narrow range of pH, pH at once becomes a sharply limiting factor. If low salinity only is tolerated, the organism is barred from the oceans and many inland bodies of water.

The bacteria of the order Beggiatoales seem to be widespread for the most part, but Bergey's Manual of Descriptive Bacteriology[1] is dubious about the distribution of some of them. In the past four years many waters of the United States have been searched for Beggiatoles and many publications have been reviewed for their distribution in other parts of the world.

The genera *Beggiatoa* and *Thiothrix* with six and seven species respectively, are easily recognized. Others are less easily recognized, primarily because they may be mistaken for other organisms, or perhaps because they are rare. Thus, we have found no references to *Thiospirillopsis* other than that of its original description by Uphof[2]. *Thioploca* is of doubtful validity; it has not been found at any location investigated by us in the past four years, and is not considered here. The fourth genus, *Thiodendron*, is new and its position and name are tentative, but it would add a new family, *Thiodendrales*. It has been found in two locations, where it appears to be a permanent inhabitant. It is included in this discussion because its occurrence is unique.

Table I gives the occurrence of the known species of the four genera mentioned. Only *Beggiatoa* and two species of *Thiothrix* have been widespread in four years of active search for members of the order. It seems then, that any ecological (indicator) use of Beggiatoales might well be restricted to *Beggiatoa* to be commensurate with time expended. Four of the six Beggiatoa species are illustrated in Figures 1 and 2.

Factors in Distribution of Beggiatoa

Four of the species, *minima, leptomitiformis, alba* and *arachnoidea* are regarded as ubiquitous, both fresh water and marine. This is in accord with our records of occurrence. In addition, *alba* and *minima*

Table I
Observed Distribution of Fifteen Species of Beggiatoales

		Fresh Water				Ocean					
		Fla.	Woods Hole	Col.	Lake Alice	Fla.	Woods Hole	San Diego	Desert Waters, Cal., Nev.	Warm Min. Springs	Thermal Waters, Other
Beggiatoa	minima	x	x	x	x	x	x	x	x	x	
"	leptomitiformis	x	x	x	x	x	x	x	x	x	
"	alba	x	x	x	x	x	x	x	x	x	x
"	arachnoidea	x			x	x	x	x			
"	mirabilis					x	x	x		x	
"	gigantea					x	x	x		x	
Thiothrix	nivea	x	x	x	x	x				x	
"	tenuis	x	x	x	x	x	x	x		x	
"	tenuissima	x	x	x						x	
"	voukii (n.e.)										
"	longiarticulata (n.e.)										
"	annulata (n.e.)										
"	marina (n.e.)										
Thiospirillopsis	floridana	xx						xx*		x	
Thiodendron	mucosum	x								x	

x = Personal Observation
xx = From the Literature
Often a single record.
(n.e.) = Not personally encountered: all these presumably from ocean or brackish waters.
* = Identity not certain. From Pacific Grove, Cal.

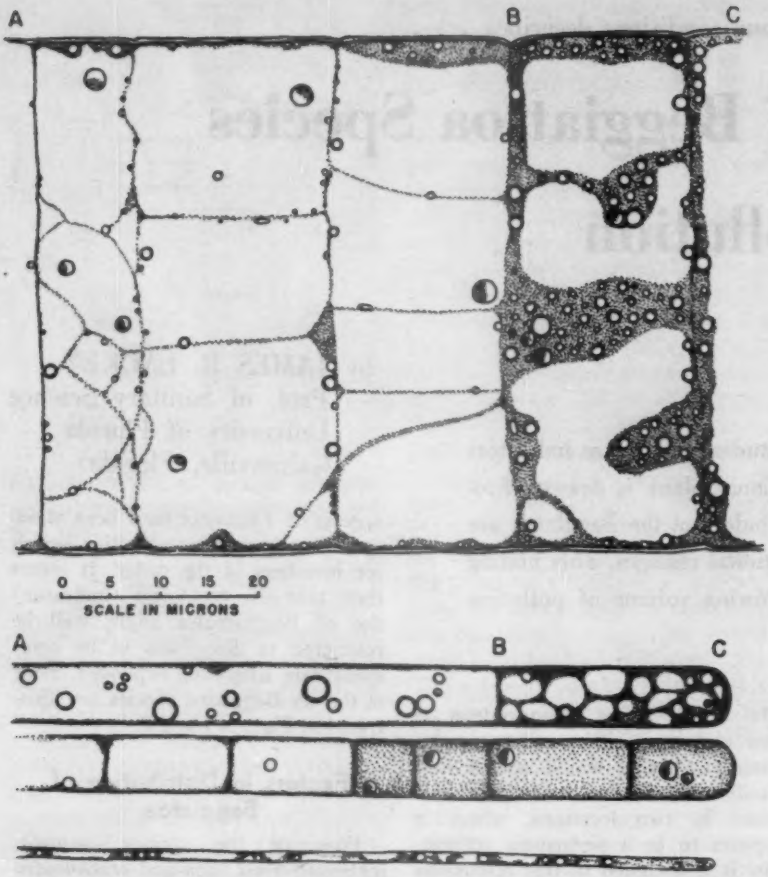

Fig. 1. THREE OF the six species of Beggiatoa. Shown are the largest, B. gigantea, a marine form, B. arachnoidea (two strands) either fresh water or marine and B. leptomitiformis. B. alba, most common species, and B. minima, the smallest, are not illusrtated. A-B is an optical cross-section showing internal structures, while B-C is a surface view.

have occurred in springs and waters around Las Vegas, Nevada, which were admittedly of high salt content, usually magnesium salts. The species *mirabilis* and *gigantea* have been found in brackish water, and in Warm Mineral Springs, Florida, which is about half sea water, 17000 ppm Ca. Obviously, they are not restricted to sea water of high salinity i.e., they would come into Dahl's[3] pleiomesohaline ecological category. They have also been found in waters whose osmotic characteristics have been due to other salts, as in some Death Valley locations. Considering their size however, it would hardly be possible for them to have been missed if they occur in fresh water.

Alkalinity

Most of the water containing *Beggiatoa* is pH 7.0 or above. In fact, bottom samples from many soft water locations have not yielded a single specimen of *Beggiatoa,* whereas many hard waters contained them in abundance. Since they are generally supposed to be anaerobes, and since they thrive in "sulfur waters" this is surprising. Hydrogen sulfide tends to produce acidity, and any marked concentration of *Beggiatoa* species is always coincident with a pronounced odor of H_2S. It is worth noting however that Wheatland[4] has shown H_2S and O_2 can co-exist in solution when the DO does not exceed 0.16 ppm; in excess of this, H_2S would not be formed, and that present would be precipitated, at least in the presence of light.

Oxygen

Oxygen then, acts as a limiting factor for the presence of *Beggiatoa* in excess of 0.16 ppm. The organisms die out rapidly in runs from sulfur springs as the water becomes aerated. There is indirect evidence also that some DO is necessary. In Warm Mineral Springs no *Beggiatoa* are found from a depth of 160 feet up to a depth of 35 feet. At this point the sides of the "chimney" recieve enough light for the growth of blue green algae, and at once sulfur bacteria (as well as many other organisms) appear. There is very little change in the amount of H_2S from 160 feet to the surface. Unfortunately no oxygen determinations have been made at these depths; Winkler determinations simply give a blank.

The need for at least a small amount of oxygen by *Beggiatoa* is shown in its use of H_2S. Winogradsky[5] who was never able to secure pure cultures, nevertheless proved that *Beggiatoa* and *Thiothrix* oxidized H_2S, and had no need for organic (carbon containing to him) matter. The type reaction is:

$$H_2S + O \rightarrow H_2O + S + 3000 \text{ Cal.}$$

This to him was respiration, and any necessary carbon must have come from CO_2. The sulfur was stored, as small "globules semi-liquids" and never took the form of crystals in living filaments. The sulfur could be further oxidized to H_2SO_4 which was neutralized in the environment. But H_2S was necessary for the life of these organisms. Subsequent to 1889 Keil[6] showed that the source of

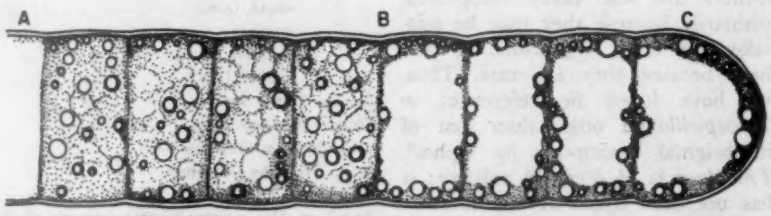

Fig. 2. A-B SHOWS optical cross-section and B-C a surface view of B. mirabilis, a marine form.

nitrogen for these bacteria could be ammonium salts, also that no CO_2 was excreted by them. They are thus autotrophs. Nevertheless in our laboratories, where we have obtained pure cultures, no growth has been obtained without some organic matter. Acetate for example produces heavy growth; however it has not been possible to transfer and get satisfactory growth. Evidently there are unanswered questions.

This autotrophic character, plus the fact that at best only a minimum of O_2 is needed by these organisms explains how they can live in highly polluted areas, yet not be indicators of pollution. In such situations CO_2, NH_3, sulfides and sulfates are usually abundant. Other bacteria can reduce the sulfates and organic sulfur compounds, and if light is present even in small amounts, some oxygen will be produced by photosynthetic bacteria, blue green algae, or any other means of oxygenation, regardless of how rapidly used. The necessary substrate materials are natural concomitants of pollution, so the Beggiatoales thrive, unless directly toxic materials are present. They can find the needed materials in situations also, where there is no pollution. The large numbers of *Beggiatoa* in the canyon off the Scripps pier may be directly related to the large amounts of sulfur in the dead and decaying kelp, *Macrocystis pyrifera*, which also accumulates there at times. Lack of a mechanism for any oxygen production in sewage digesters may explain the absence of *Beggiatoa* there, whereas it is often abundant where some aeration is present, as in Hayes treatment plants.

Light

Light does not seem to have any other direct affect on the distribution of *Beggiatoa*. However, in our laboratory it has been observed that gross cultures in a jar containing considerable debris will crawl into the debris, when in the light, but if the jar is put in the dark, within an hour the bacterium will have crawled out upon the top of the debris. This has been tested repeatedly only for *B.alba*. It is in direct contrast to the behavior of certain blue green and green algae which are positively phototactic.

Pressure

Hydrostatic and atmospheric pressures within the ranges 0 to 120 feet in the ocean, and 270 feet below to 9000 feet above sea level respectively are not preclusive. *Beggiatoa* has been found in the canyon off the Scripps pier at 120 feet, and there is often a white coating on parts of the canyon floor. Species of the genus have also been found in Death Valley and above 9000 feet in the Colorado Rockies.

Temperature

Temperatures ranging from about 10°C. to about 50°C. have been noted in the field, where *Beggiatoa* was abundant. At Pagosa Hot Springs in Colorado, *Beggiatoa* occurred in water hardly tolerable to the hand. Dr. Roger Mitchell of the Univ. of Florida biology staff has supplied material from various thermal springs in the Pacific Northwest which contain blue green algae and *Beggiatoa*.

Thiodendron was originally found only in Warm Mineral Springs, and since a great many areas had been sampled for sulfur bacteria, it was thought that this might be a salt or brackish water form restricted by temperature, which is fairly constant at 28.5°C. in this spring. Subsequently one of the staff brought in a collection of sulfur bacteria from a highly polluted area behind a crab-packing plant at Titusville, Florida, on the inland waterway. This proved to contain *Thiodendron*, which has been repeatedly collected there, at temperatures from about 10°C. to 24°C. This area is polluted, often heavily; Warm Mineral Springs is not. About the only common factor is that both situations have about 17000 ppm sea salts.

Summary

It is seen from Table 1 that *Beggiatoa* species are widespread. Only two species, *mirabilis* and *gigantea* apparently are restricted to brackish or salt water. A brief look at environments in which all six have been found indicates their tolerances for environmental factors are rather wide with one exception. That is an absolute necessity for some H_2S, and traces of O_2. And they are not satisfactory indicators of pollution.

Acknowledgment

This work was done under the terms of a grant-in-aid from the U.S. Public Health Service.

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Oligochaetes As Indicators of Pollution

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RESUME: Abundance of Oligochaetes in polluted stream bottoms has led to a study designed to produce a rapid biological indicator of pollution. This report describes progress to date and direction in which research is progressing.

■ THE NEED FOR a fast, simple biological indicator for stream pollution has long been recognized. Several methods have been explored, and while all are valuable, most were found to involve complicated taxonomic problems. At the present time, we are investigating a system which may meet the standards desired without the usual identification problems.

At first observation in a polluted area, the bottom often appears to be a dull red color. This color is due to the presence of thousands of oligochaetes, small aquatic annelid worms, of the family Tubificidae. So often are these worms associated with pollution that they have obtained various common names such as "sewer worms", and "sludge worms". It has come to our attention that the abundance of these worms in relation to the total bottom fauna might provide a system for the recognition of the degree of pollution in streams or drainage ditches.

In investigating this phenomena a drainage ditch southeast of Lafayette, Indiana, was selected for study. This ditch is of average size, and has the important characteristic of having relatively clean stretches of water as well as areas of domestic and industrial pollution.

The study being made consists of determining the physical and chemical characteristics of the ditch water and includes such measurements as the amount of dissolved oxygen, carbon dioxide free in the water, coliform analysis, total hardness, calcium hardness, pH and B.O.D. These factors have been determined at each of seven stations along the ditch. Samples have been collected weekly from June to November, 1959, and bimonthly from the first of November until the present time (March, 1960) The collections will be continued until July, 1960. We feel that these determinations will give us a fairly complete picture of the water characteristics of the ditch in all seven areas.

In conjunction with these limnological samples, samples of the bottom fauna at each of the seven stations have been taken in the field and brought into the laboratory. The same collection periods were used, both water and bottom samples taken at the same time. In the laboratory, the bottom samples are rinsed through four standard sieves to remove mud and sand. These sieves are then set into pans of water and the bottom samples sorted by hand to remove all the fauna. Quantitave tabulations are kept on the forms and their abundance in the sample. The forms are then stored in preservative for future reference.

At the present time, this study has not progressed far enough to draw concrete conclusions. We do feel, however, that the possibilities are excellent that these worms may be used as the basis of a system which will allow a person with only a basic knowledge of biology and without special taxonomic training to take samples of a small stream or ditch and to determine whether or not polluted conditions exist.

In addition to the detailed study of this one ditch, samples are being taken in other streams throughout Indiana. This will provide a further check on the validity of the system for identifying polluted areas.

Colonies of these worms are also being raised in the laboratory so that investigations of the effects of various pollutant factors on their reproductive rate may be investigated.

This work is being done under a grant from the National Institutes of Health.

The Destruction of Alkyl Benzene Sulphonates in Sewage Treatment Processes

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■ IN THE UNITED KINGDOM, the use of synthetic detergents on a large scale may be said to have begun about 1949. Table 1 illustrates the rapid rate of growth in the period 1949-1955, followed by a comparatively slow increase. The greater proportion of this surface-active material is used in the home and is therefore discharged to sewers without restriction. Most of it is in the form of packaged detergent powders based on alkyl benzene sulphonates. Figures given in Table 2 illustrate the relatively small proportion used in the form of liquid detergents in 1958. Moreover, most of these liquid detergents were based on biologically attackable or "soft" surface-active materials. The bulk of the surface-active material entering the sewers, therefore, is derived from packaged washing powders in which the active ingredients, in 1958, was sodium tetrapropylene benzene sulphonate (sodium Dobane PT suphonate).

It soon became apparent that the new synthetic detergents were not completely removed at sewage treatment works. In particular, the large-scale introduction of these materials in a district was often followed by complaints of excessive foaming at the local sewage works and in the rivers to which their effluents were discharged. In addition, it was claimed at some sewage works the efficiency of treatment had been reduced and consequently, the quality of the final effluent had deteriorated. The persistence of the surface-active material was also illustrated by its appearance in some river-derived water supplies.

In view of these and similar observations, an official Committee was set up in 1953 to consider generally the effects of the increasing use of synthetic detergents on public health. The Committee, known as the Jephcott Committee, after its Chairman, Sir Harry Jephcott, issued its final report in 1956[1]. This contained a number of conclusions and recommendations. One stated that manufacturers should investigate the possibility of producing efficient washing products based on materials which would be eliminated and which would not cause foaming during sewage treatment.

About the same time, a number of aspects of pollution by synthetic detergents were studied at the Water Pollution Research Laboratory. Among other findings the following effects were established:

a. In a laboratory-scale activated-sludge plant introduction of sufficient packaged detergent to give a concentration of 10 ppm, as Manoxol O.T., in the sewage had no detrimental effect on the quality of the effluent provided that aeration was adequate. However, the dissolved oxygen content of the mixed liquor fell from 5.2 to 3.3 ppm[2], representing a reduction in the absorption coefficient for oxygen in mixed liquor of about 37 per cent. When the rate of aeration was reduced to a level at which nitrification was incomplete, introduction of the same concentration of detergent resulted in an increase in the ammonia concentration of the effluent with a simultaneous reduction in the concentration of oxidized nitrogen. To restore the efficiency of the plant to its original level, it was found necessary to increase the flow of air by 2-3 times. These experiments confirmed to some extent the complaints of reduced efficiency at large-scale sewage treatment works.

b. A solution of packaged synthetic detergents equivalent to 3 ppm as Manoxol OT in clean well-oxygenated water produced about 50 per cent mortality among rainbow trout in about 12 weeks[4]. When the concentration of dissolved oxygen was reduced to near lethal levels, the same concentration of detergent rendered the fish more susceptible to lack of oxygen. Similar concentrations of synthetic detergent remaining after biological treatment of sewage were much less toxic, and residues equivalent to 3 ppm Manoxol OT had no detectable effect on susceptibility to oxygen in this country surface-active materials in sewage effluents were unlikely to represent any serious danger to fish.

*All concentrations of surface-active material referred to in this paper were determined by the method of Longwell & Maniece[3] and are expressed in terms of Manoxol O.T. (sodium dioctyl monosulphosuccinate).

Table 1
Consumption of Synthetic Surface-Active Materials In The United Kingdom

Year	Thousands of Long Tons Domestic	Industrial	Total
1949	10.5	2.5	13.0
1950	12.5	2.7	15.2
1951	14.0	3.8	17.8
1952	21.0	5.2	26.2
1953	29.0	6.0	35.0
1954	33.0	6.0	39.0
1955	34.0	6.5	40.5
1956	34.5	6.5	41.0
1957	34.1	6.9	41.0
1958	35.0	7.3	42.3
1959	37.5	7.4	44.9

Preliminary Testing of "Soft" Alkyl Benzene Sulphonate

By 1958 a new type of alkyl benzene sulphonate, which seemed to meet the requirements of the Jephcott Committee, had been produced by the manufacturers and was made available in small quantities for testing. Preliminary tests by the London Metropolitan Water Board and by the Laboratory of the Government Chemist confirmed that the new material, sodium Dobane JN sulphonate, subsequently referred to as "soft", was more readily removed by biological action than the original, "hard" material. A comparison of the rates of removal of the old and new materials when incubated with river water is shown in Fig. 1.

Examination of the infrared absorption spectra of the two materials at the Laboratory of the Government Chemist suggested the "soft" material had a less branched carbon chain and that it contained substances such as those shown at c and d in Fig. 2. Typical constituents of the "hard" material are shown as a and b in the same figure.

In view of the promising results obtained in the preliminary tests, the Standing Technical Committee on Synthetic Detergents, the successor to the Jephcott Committee, requested the Water Pollution Research Laboratory to carry out a more extensive investigation to determine the behavior of the new material in sewage treatment processes.

For this purpose, equipment (Fig. 3) was set up to reproduce in the laboratory sewage treatment by activated sludge and biological filtration. Since all sewage available in this country contains surface-active material, arrangements were also made for the production at the laboratory of a detergent-free sewage at the rate of several hundred gallons per week. Comparative tests were then carried out in which sewage containing either the "hard" or the "soft" detergent was treated in replicate units. Detergents used in these experiments were supplied by the manufacturers in the form of packaged washing powders. These were added to the detergent-free sewage in the proportions necessary to give a concentration of 13 ppm as Manoxol OT, an average figure for surface-active material in sewage in the U.K.

Results obtained at equilibrium summarized in Table 3, illustrated the greater degree of removal of "soft" material in sewage-treatment processes and suggested that, if this material were to replace completely the "hard" material, the concentration of residual surface-active material in sewage effluents and rivers would fall to about one-quarter of the present values, provided, of course, the degree of removal achieved in the laboratory could be reproduced on the large-scale. These experiments have been described in greater detail elsewhere[5].

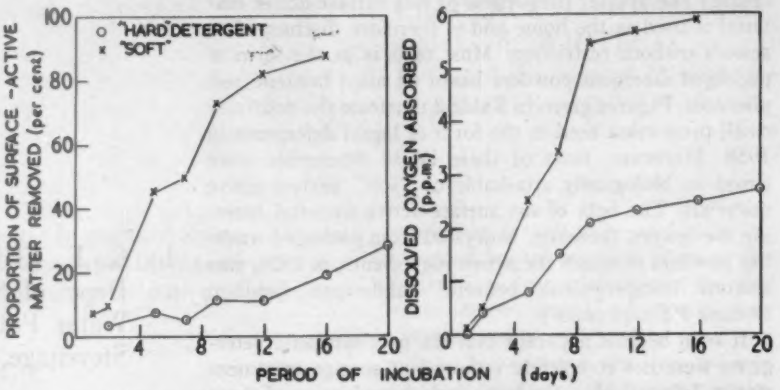

Fig. 1. BREAKDOWN OF surface-active materials on incubation at 20°C with an oxygenated river water. Initial concentration about 8 ppm, as Manoxol OT.

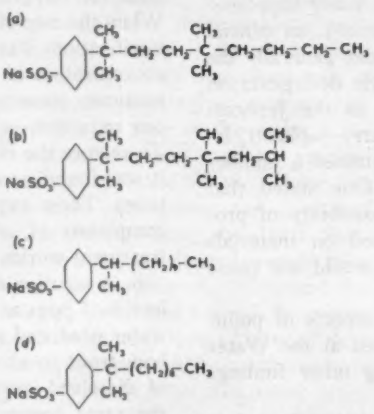

Fig. 2. THE ORIGINAL "HARD" sodium tetrapropylene benzene sulphonate, sodium Dobane PT sulphonate, consists of compounds such as (a) and (b). The "soft" material, sodium Dobane JN sulphonate, contains compounds with structures such as (c) with perhaps some of type (d).

Table 2
Estimated Consumption of Liquid Detergents In The United Kingdom During 1958

	Thousands of Long Tons
Primary alkyl sulphates	0.48
Secondary alkyl sulphates	1.52
Alkyl benzene sulphonates	
biologically "hard"	0.51
biologically "soft"	0.71
Non-ionic	0.98
Total active matter	4.2

The resistance to further oxidation of the residual surface-active material derived from the new product was determined by aerating samples of effluent in open vessels for periods up to 20 days. Although some further oxidation occurred it appeared that some 0.5 ppm (4 per cent) was resistant to further attack. No further oxidation occurred when effluents derived from sewage containing the old material were aerated under the same conditions.

During this work the foaming properties of the various effluents were determined using an arbitrary test[6] in which the height of foam produced under standard conditions of aeration was measured. Effluent from the treatment of sewage containing the new detergent contained comparatively low concentrations of residual surface-active material and produced amounts of foam which were not significantly greater than those produced from the detergent-free ef-

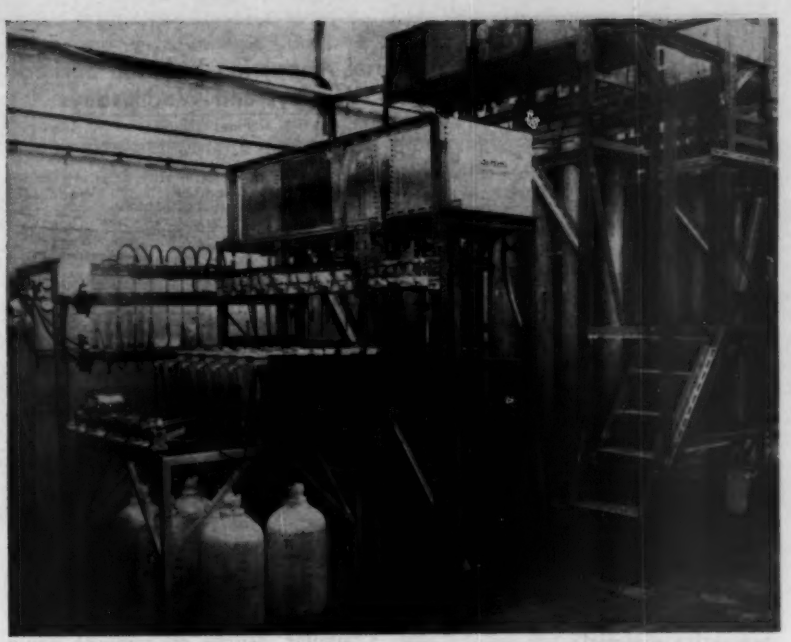

Fig. 3. APPARATUS USED in tests on the removal of detergents from sewage. Activated-sludge units are on the left and percolating filters on the right.

fluent. Effluents from sewage containing the "hard" detergent contained higher concentrations of residual surface-active material and gave considerably greater amounts of foam.

Subsidiary experiments showed that while, weight for weight, the effect of the "soft" detergent on oxygen transfer was similar to that of the old, the greater degree of removal during sewage treatment resulted in a smaller adverse effect on the overall process efficiency. Toxicity tests on effluents from sewage containing the "soft" detergent showed these were virtually non-toxic to rainbow trout.

It should be added that the sewage-treatment processes were operated under favorable conditions and were giving highly nitrified effluents. The removal of synthetic detergents under conditions of overloading and uneven loading is still being investigated.

The results were considered sufficiently promising to justify the use of the new "soft" material on a larger scale, and the Committee decided to take advantage of an offer by the manufacturers to produce the new materials in the quantities required for a large-scale experiment.

Large-Scale Trials—the Luton Experiment

The aim of this experiment was to replace a large proportion of the synthetic detergent used in a typical town by the new material, and, by studying the resulting changes in the concentration of detergent in the sewage and final effluent, to ascertain whether the results of the laboratory tests would be repeated under full scale conditions. For various reasons, Luton, an industrial town having a population of 120,000, was chosen for the experiment which was begun in the autumn of 1958. The new material was used by the three major manufacturers in the formulation of their normal brands of washing powders which were supplied to the town through the usual retail channels. It was decided initially that the fact that this experiment was being conducted should not be disclosed, the object being to prevent changes in the patterns of purchase and use of detergents by the general public. Information about the experiment was first made public in reply to a question in Parliament on 28th July 1959.

Sewage from Luton undergoes comprehensive treatment by primary sedimentation, a high-rate activated sludge process, biological filtration, and secondary sedimentation, followed by microstraining or sand filtration before discharge to the River Lee. Further downstream the river serves as a source of about 15 per cent of the London water supply.

Before the experiment began, assessments were made of the amounts of surface-active material appearing each day in settled sewage, and leaving the works in the final effluent. For this purpose automatic samplers were set up to take samples at 2-hour intervals throughout the 24 hours. In view of sampling difficulties, no attempt was made to assess the amounts of surface-active material entering the works in crude sewage. As time was limited, attention was concentrated on the three days of the week, Monday, Tuesday,

Table 3
Removal of "hard" and "soft" Alkyl Benzene Sulphonates (ABS) During Biological Treatment of Sewage In The Laboratory

	Initial Concentration 13 ppm (as Manoxol OT)			
	Biological Filtration*		Activated-Sludge Process†	
ABS	Percentage removed	Residual Concentration (ppm)	Percentage removed	Residual concentration (ppm)
Hard	67	4.3	69	4.0
Soft	94	0.9	94	0.9

*Rate of application 1.16 million U.S. gal/acre day
†Retention period 6 hr
Suspended solids 3000 ppm

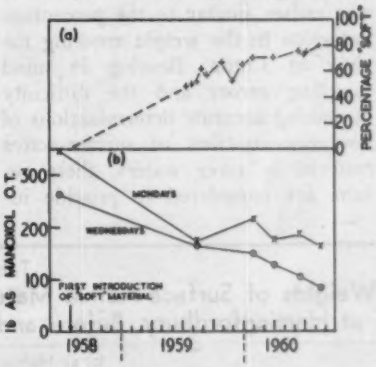

Fig. 4. PROGRESS OF the Luton Experiment. (a) Percentage "soft" in detergent content of settled sewage. (b) Weights of surface-active material discharged daily in final effluent.

and Wednesday, on which it was thought the worst effluents would be produced. During this period, June and July 1958, exceptionally wet weather was experienced and only on 5 occasions were 24-hour sampling runs completed without interference by rain. Satisfactory agreement was obtained between duplicate sets of results for Monday and for Wednesday.

Introduction of the new material was begun early in August 1958. An account of the experience of the manufacturers in making this changeover has been given by Squire[8]. As replacement of the "hard" by the "soft" material proceeded, samples of the settled sewage were examined by the Laboratory of the Government Chemist using infrared spectroscopy to distinguish the two types of material[9]. Typical results are shown in Fig. 4.

Measurements of the weights of surface-active material in settled sewage and in filter effluent on various occasions during the experiment are shown in Table 4. An interesting feature of these results is the marked decrease in the weight appearing in the settled sewage. This could not be accounted for by a reduction in sales and is attributed to losses by decomposition of the new material in the sewers and primary sedimentation tanks. These losses are additional to the losses of surface-active material which are known to occur during primary sedimentation. Decomposition was also found to occur when Luton sewage, containing a proportion of the new material, was allowed to stand in the bottles of the automatic samplers overnight; losses of up to 20 per cent were observed. This decomposition was prevented by adding to each sample bottle before use sufficient mercuric chloride solution to give a concentration of 10 ppm $HgCl_2$ in the sample.

Table 4 also illustrates the decrease in the weight of surface-active material discharged in the final effluent on a given day as the replacement of "hard" by "soft" material proceeded. Fig. 4 shows how these weights have decreased as the proportion of "soft" to "hard" detergent in the settled sewage has increased.

Table 4
Weights of Surface-Active Material Appearing In Luton Settled Sewage and Final Effluent On Mondays and Wednesdays

	Settled Sewage		Final Effluent	
	lb as Manoxol OT			
Date	Monday	Wednesday	Monday	Wednesday
June-July 1958*	1120	746	346	262
Aug. 10-12 1959	766	693	174	165
Feb. 1-3 1960	778	601	217	148
April 4-6	844	611	177	128
June 13-15	792	514	186	104
August 15-17	708	402	165	82.5

*Mean of two sets of results

Effect of the New Detergent on the River Lee

For several months before the introduction of the new detergent at Luton, and throughout the experiment photographs have been taken regularly at two places on the River Lee at which foam is generally present, namely at Wheathampstead Mill and at Lemsford Mill. Samples of river water have been taken at the same times for determination of surface active material.

During March-July 1959 the amount of foam shown in photographs of the river at Lemsford was appreciably less than the amount at the same times in the previous year, as judged by a panel of observers to whom the photographs were shown in a random and undisclosed order. This apparent improvement, however, was not subsequently maintained and there appeared to be little correlation with the concentrations of surface-active material determined by analysis.

Some estimates of the amounts of surface-active material passing down the River Lee at Hertingfordbury, some 15 miles below the Luton effluent outfall, during the months of April to September in 1958 and 1959[10] are given in Table 5. The was rather similar to the percentage reduction in the weight entering the river at Luton. Bearing in mind sampling errors and the difficulty of making accurate determinations of low concentrations of surface-active material in river waters, these results are considered to provide independent evidence of the reduction in the detergent content of the River Lee as a consequence of the Luton experiment.

Conclusions

On the basis of the laboratory experiments, it was estimated that if a similar degree of removal could be achieved on the large scale, the replacement of all the surface-active material used in Luton by the new "soft" material would result in a reduction in the weight of detergent residues discharged to the River Lee to about a quarter of the former value. This result has not yet been achieved, partly because of the less efficient removal of surface-active material at the sewage works as compared with removal in laboratory plant and partly because the original "hard" material has not yet been completely replaced by "soft". This incomplete replacement may be attributed to the introduction of "hard" material in forms other than the packaged products of the major manufacturers, for example, scouring powders, and to the time required for the using up of household stocks.

Since September 1959 detergents containing the new "soft" material have been supplied to a much larger area in the south of England. The effect of this will be to reduce the amount of "hard" material reaching the Luton area and gradually to in-

Table 5
Weights of Surface-Active Materials Passing Down The River Lee at Hertingfordbury, Before and During the "Luton Experiment"

lb as Manoxol OT per day

Year	April	May	June	July	August	September	Mean
1958	318	258	213	209	197	216	235
1959	244	151	164	133	141	134	161
Percentage reduction	23	41	23	36	28	38	31

crease the probability of a more decisive conclusion to the Luton experiment.

Finally, it should perhaps be pointed out that the "soft" material studied in these tests is only one of many substances which have satisfactory properties as detergents and which are broken down in sewage treatment processes. The Luton experiment, though not yet completed, already indicates it may be possible to manufacture on the national scale detergents which are acceptable to the housewife and which minimize the problems in sewage treatment and water supply which resulted from the introduction of the original synthetic detergents.

Acknowledgments

This paper summarizes briefly the work of many members of the staffs of the manufacturers of synthetic detergents, the Metropolitan Water Board, the Laboratory of the Government Chemist, and the Water Pollution Research Laboratory. Facilities for sampling and photography were provided by the Borough of Luton, Harpenden Urban District Council, and the Lee Conservancy.

Much of the work described in this paper was carried out on behalf of the Standing Technical Committee on Synthetic Detergents. The paper is published by permission of the Department of Scientific and Industrial Research.

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Radical new techniques may be required to keep up and cope with . . .

Our Changing Environment

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EDITOR'S NOTE: Past progress in public health must be recognized as getting us where we are today. Industrial research is creating new, different and unusual problems which add to the complex of population growth and its allied problems. Relatively new contaminants in the air and on the ground will no doubt require new techniques. The warning is sounded here, together with some PHS programs now in operation.

■ THE CONCEPT OF compressing time and viewing the human species as a few weeks old sharply outlines human progress. If we assume an interstellar reporter from a superior civilization whose days equaled about 1,000 of our years, and assume further that they discovered the earth at about 5,000 B.C., then, to paraphase Ralph V. Smith (1), here is how the report might read:

> Seven days ago we first reported that there was life on a planet in a minor solar system. The more intelligent denizens inhabited caves, hunted others for food, used stone tools, and knew the lever principle. For two days there was no change. On the third day, our observers reported that the inhabitants had learned to build with lumber and rock, and had begun to use lesser denizens to supply power. On the fourth day, wheels and bronze tools came into use. On the fifth day iron tools were in use and canals and reservoirs were seen. Late that day the alphabet was invented.
>
> On the sixth day, geometry, screw and pulley, the stone arch, and coal were in use. Yesterday, algebra, trigonometry, and the compass became available. Magnetism and chemistry were being investigated.
>
> Today, the eighth day of our observations, progress is accelerating. At about midnight, the printing press was invented and a new land mass was discovered. At 6:00 a.m., the similarity of electricity and lightning was noted. At 7:00 a.m., steam was first used for power. By 8:00 a.m., the relation between electricity and magnetism was established, and the electric motor came into use. Between 9:00 and 10:00 a.m., the typewriter and linotype were devised; a new furnace came into use, and aluminum became available; the light bulb was devised, and electric generating plants were built; the telegraph and telephone became available, and soon thereafter radio.
>
> Between 10:00 and 11:00 a.m. airplanes, motion pictures, radio and television broadcasts, the theory of relativity, and nuclear power came into being. Stand by for further developments.

Now, in this recital of human progress, no mention is made of food preservation, population increase and concentration, the automobile, water use and abuse, nor of man's problems with his environment.

We are in the "eighth day of change" in our environment. Figuratively, the field of public health came into being at 10:00 a.m. The pace is not slow. The change in environmental hazards from epidemics of disease to the finite closing-in of our environment is subtle. Today, we deal increasingly with nonliving contaminants in water and air, and with radiological health problems.

Past achievements in public health have been many. For example, typhoid fever and dysentery are waterborne diseases. Much of the nation's infant mortality rate stemmed from such waterborne diseases, and from raw milk and other unsanitary environmental conditions. Yet infant mortality has been sharply reduced from 100 per 1,000 live births in 1915 to about 25 today. A major share in the conquest of the communicable diseases can be assigned

to the application of sanitary engineering practices in water supply and water pollution control, milk and food sanitation, insect and rodent control, industrial hygiene, and related fields.

In an ever-changing environment new problems must be anticipated and attacked before *finis* is written to the old. We are facing problems of increasing complexity in the change from an agricultural to an industrial economy, from a rural to an urban people, from a young to an older population, all concomitant with an explosive increase in population and production and an unprecedented acceleration in technology.

Today, we produce three times as much in a 40-hour week as we did 100 years ago in a 70-hour week. Projecting this increase in production to the year 2000, we should be able to produce in a 7-hour day what we now produce in a 40-hour week.

The accelerated rate of production has included the rise of completely new industries. Among those not mentioned by the intersteller reporter are plastics and rocketry. Most of this industrial production adds to our comfort and well-being. On the reverse side of the coin, such production adds problems of waste disposal and pollution that threaten our health through contamination of the environment.

The problems of water supply and water pollution control continue to present a constellation of complexity. For example, some 400-500 new chemical compounds are introduced annually to the market. Thus, pesticides have contributed to the control of vectorborne diseases such as malaria, typhoid, trachoma and dysentery. The Public Health Service, U. S. Department of Health, Education and Welfare, estimates that 5 million lives have been saved in this country since 1942 through the use of insecticides. At the same time, these pesticides and insecticides are helping to increase food production by making the land produce more and reducing crop losses. However, pesticides are adding to the problems of our changing environment, even while they are helping us conserve human life and providing more food.

There is the possibility that many of these substances, including insecticides, fungicides and weedicides, can reach the food-consuming public by leaching into ground water or running off in streams used as drinking water supply sources.

Similarly, the development of new industries—electronics, plastics and missilery are representative—involves new manufacturing processes and even the use and creation of new chemical substances. These conditions have drastically changed the nature of waste products which enter the nation's streams. The wastes of earlier times were bacterial and biologic in nature and susceptible to known waste treatment processes. Those of today are non-bacterial and chemical. Many of these organic, synthetic wastes are complex, defying separation and analysis. They are generally not subject to inactivation (as by disinfection or heat). They are predominantly man-made. Most important, they are generally cumulative. This latter observation suggests that, though nontoxic in trace amounts at present, their cumulative effect over time must be considered. When placed against the realization that water purification processes are designed primarily to control biological contaminants, the need to consider more intensively and extensively the effects of chemical contamination becomes pressing and urgent.

As the population increases and industry expands, the need for water rises. Forty billion gallons of water a day was used in 1900. Today we use 270 billion gallons per day. In 1980, an estimated 600 billion gallons per day will be needed.

The increased use of washing machines for clothes and dishes, air conditioning, and other modern appliances is raising the amount of domestic water consumption. The industrial production necessary to keep pace with the demand of a growing population for domestic appliances and the newer industries is likewise raising the amount of water consumption.

Research designed to increase the amount of water available through desalting processes, the prevention of evaporation, and cloud-seeding are all possibilities; but the treatment and re-use of waste water is given major emphasis. It is, however, increasingly difficult to control water pollution, not merely because of increased population, detergents, and the new complex wastes, but also because waste treatment facilities construction has fallen behind. The construction grant program of the Public Health Service is designed to help meet the needs in this area.

A first major blueprint of the nation's polluted streams is emerging through the National Water Quality Network which was instituted a few years ago by the Public Health Service. Organized, maintained, operated and financed jointly by the Federal Government and state and local agencies, approximately 60 sampling stations of an anticipated total of 250 have been established at a number of water courses for the examination of radioactivity, plankton and coliform organisms, organic chemicals, and for carrying on a number of biochemical, chemical and physical measurements. Local laboratories are performing conventional chemical analyses. The more complex examinations are made by the Public Health Service. The Service is also making all results available to collaborating agencies and other interested groups.

The publication of the first year's data gathering operation has recently become available. A companion volume of analysis and summarization is in press and will be out early in 1960, together with the compilation of the second year's data. The plan is to issue annual documents within three months following the "water year"; namely, every January-March.

Concurrent with such an inventory water research revolves about such questions as the following: having identified a new waste, can its pollutional effects be predicted? In disposing of waste effluents, is effective use made of the receiving water? Can polluted water be effectively treated for re-use? Studies underway or under consideration in various governmental and university laboratories include the use of stabilization ponds, investigation of bio-oxidation surfaces, the treatment of sewage by anaerobic contact, the role of water in the transmission of viral diseases, and the role and functions of algae and fungi.

Water is not the only problem either created or intensified by the changing environment. Air pollution once a simple matter of smoke abatement, is now complicated by automobile exhaust fumes, combustion

from a new variety of industrial processes, and the "lid" that air inversion can put on these noxious fumes. When the photo-chemical reactions of sunlight with these air contaminants take place, we have a modern problem, acute air pollution.

Our environment is reminding us that the air and water resources are finite in their ability to absorb, disseminate and render innocuous the waste products from our modern technological society.

Thousands of communities in the United States have air pollution problems in varying degrees, involving deterioration of paint and rubber, blighted crops and livestock, reduced visibility that causes accidents, and eye irritation.

The economic losses from air pollution in the United States alone are estimated to be between $2 and $4 billion annually. Of even greater concern, however, is suspected chronic health impairment. This is not subject to easy measurement, and is not established. Are individual air pollutants harmful to humans? Are certain combinations of pollutants harmful? These are questions for which answers ultimately must be found.

Radiological health is another of the most important of the new problems. It has been estimated that in about 20 years, one-third of newly-installed electrical power will be generated at nuclear plants. The use of radioisotopes in sanitary engineering, medical, industrial, agricultural and other scientific research is continually increasing. Radioisotopes are being used as tracers, arc initiators, fluid interface indicators, and thickness gages.

Sanitary engineers are using radioisotopes to study the role of algae in the natural cycle of waste recovery in streams; to study corrosion; to determine the capability of slimes to adapt to and cope with certain organic wastes; to treat sewage; and to make more complete chemical assays of water through activation analysis.

The crux of this host of new problems we face lies in the long-range physiological effects on people of these new subtle and insidious contaminants in our water and air. A stepped-up research tempo is necessary to provide new principles of environmental control.

The sanitary engineer must apply himself diligently to the solution of these problems. Other specialists in the public health fraternity have important contributions to make. In either case, it is the sanitary engineer who will apply the remedies found. The need for sanitary engineers and the importance and scope of their work are growing constantly. Air pollution and radiological health, the most recent problems of our changing environment, are prime examples of why sanitary engineering skills are needed and are broadening.

The need to master more knowledge in the engineering and basic sciences has led a number of people to believe that a longer period of study is necessary to produce a sanitary engineer. A fifth year of study would be indicated to train a sanitary engineer. This, of course, involves the provision that allied professional personnel also become available.

One of the early English poets said, "No man is an island unto himself." In today's complex world, this is a truism. The interdisciplinary and multidisciplinary approach is an absolute necessity, if we are to get anywhere with present day problems.

A recent survey of 4,000 sanitary engineers (2) revealed that about 40 percent had a Master's Degree or better. Only one percent of the respondents, however, listed air pollution as their primary speciality, and only 0.5 percent listed radiological health.

It thus becomes obvious that trained manpower must be made available if we are to meet the stern demands of an era of rapid environmental change.

As we approach midnight in the time of our figurative intersteller reporter, and try to conquer outer space, we must be prepared to meet the new hazards resulting from our changing environment.

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Separated industrial and residential area assists . . .

Research in Water Pollution

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EDITOR'S NOTE: The siting of a laboratory in a fast-growing suburb outside of London has made it possible to investigate, individually, both domestic and industrial waste water flow. The author reports briefly on laboratory research into biological degradation of synthetic detergents, characteristics of domestic sewage flow, solving tannery wastes problems, and treating cyanide wastes.

■ THE PROBLEMS of water pollution are becoming acute in most civilized countries because of the rapid increase in size of many cities and a similar spread of industry. But in no country is the problem more acute, or more closely studied, than in Britain. Here the comparatively small size of the country and the expansion of the non-agricultural population and industry provide ample reason for intensive research in all phases of water pollution.

For more than a quarter of a century, the Government's Department of Scientific and Industrial Research has maintained a special Water Pollution Research Laboratory, which is charged with finding quick and efficient answers to problems as they arise.

About five years ago, this laboratory was moved to a new site in the still, fast-growing satellite town of Stevenage, about 30 miles north of London. This siting has proved most effective since it permits individual studies to be made of industrial and domestic water usage and waste. The layout of this "new town" provides for the complete segregation of the industrial section from the residential parts. This has enabled field stations to be established to watch the sewers of each.

Synthetic Detergents

In its latest report, this laboratory offers solutions to some of the most urgent problems facing sanitary engineers. One which gets special mention in the report is that of removing synthetic detergents from streams and sewers. A special pilot plant was set up during the year to tackle this problem.

Three years ago, when synthetic detergents were proving to provide many major difficulties for sanitary engineers, manufacturers of household synthetic detergents were urged to investigate "the feasibility of producing efficient washing products based on materials which could be readily oxidized or eliminated, and would not cause persistent foaming, during sewage treatment by present available methods."

As a result of much work by detergent manufacturers, a new anionic surface-active material has been developed. Tests have been made at the laboratory to compare the behavior, during biological treatment of sewage, of this new material with that of the type in present-day use.

In these tests, 12 similar percolating filters (each 6 ft. deep and 6 inches in diameter) and eight small continuous-flow activated-sludge units, were operated to simulate as closely as possible conditions obtained at sewage works. The detergent was added to detergent-free sewage (about 240 gal. being prepared daily) which was treated in some of these experimental plants; other units were used as controls treating the detergent-free sewage only.

It was found that when a steady state had been reached in the treatment processes, about 90 per cent of the new type of detergent was removed, compared with about 68 per cent of the type of material at present marketed. This would mean that in settled sewage containing 10 mg/L of the present type of surface-active material, about 3.2 mg/L would appear in the effluent. However, if the active material in the sewage was of the new type, then the concentration in the effluent would be only about 1 mg/L.

The amount of foam produced by the effluent from the treatment of sewage containing the new detergent was no greater than that formed by the effluent from the treatment of sewage which contained no detergent.

On the subject of foaming of liquids containing synthetic detergents, the laboratory's scientists point out that foaming is probably the most conspicuous effect of the present synthetic detergents in sewage, both at sewage-treatment works and in rivers to which sewage effluents are discharged.

A study has been made of the amount of foam produced in relation to the character of the liquid and concentration of detergent using a simple test developed for comparing the foaming tendencies of samples of sewage and effluent. The method, which measures the height of foam above a column of liquid, aerated under standard conditions, has been adapted for the rapid routine testing of samples containing synthetic detergents; the reproducibility of the method is good.

When the liquid is allowed to foam to its maximum height before the column breaks and collapses, the amount of foam produced in a given liquid increases linearly with the concentration of active agent. The tendency to foam is greatest in clean water, becoming progressively less as the amount of polluting matter in the liquid is increased. There is a constant relation between the weight of active matter lost from solution and the volume of foam formed.

The active ingredient of the synthetic detergents commonly used by housewives and therefore present in sewage is an anionic surface-active material. Compounds of this type form a complex with methylene blue dye which is soluble in chloroform.

The method used for determining synthetic detergents in liquids at the laboratory is: a solution of methylene blue is added to a suitable volume of sample and the complex formed is extracted by shaking with chloroform. The chloroform layer is then separated and the blue color produced in it, which is proportional to the concentration of detergent, is measured with a photoelectric absorptiometer or spectrophotometer using an orange filter and wave length of 650 mu.

Per Capita Sewage Flow

As previously explained, the scientists are able to make separate studies of industrial and domestic sewage. Crossing the site of the laboratory is a sewer which drains a residential district of Stevenage New Town. The sewage, which is used for experimental purposes in the laboratory, contains no industrial wastes and no surface drainage.

The opportunity has been taken of examining variations in the rate of flow and composition of this sewage throughout several periods of 24 hours. The highest rates of flow, about three times the average, occurred before noon. The greatest polluting strength and concentrations of anionic detergent were observed around noon and were about twice the respective average values. Peak ammonia concentrations, however, occurred at about 8 a.m. with smaller peak at midnight.

Since the number of people served by the sewer is accurately known the information collected in the surveys has given fairly precise values for the volume of sewage (25 gal.) and the oxygen demand (0.1 lb) discharged daily by one person.

Industrial Wastes

Among the many industrial water pollution problems were those created by waste from tanneries and those containing cyanide.

Waste waters from the tanning of leather are well known to be highly polluting. Some liquors contain a high concentration of suspended matter and are strongly alkaline owing to the presence of free lime; they may also contain appreciable concentrations of sodium sulphide. Experience has shown that, if these liquors are discharged to a sewer, troublesome deposits of calcium carbonate may form; the sewer atmosphere may be made toxic to workmen owing to the presence of hydrogen sulphide, and concrete and metal work in the sewerage system may be attacked or heavily corroded. Other liquors may contain metal salts which interfere with the biological treatment of sewage.

The laboratory has investigated possible methods of pretreatment to remove suspended matter, toxic metals, and sulphide and to neutralize the wastes at the tannery. Sedimentation, followed by chlorination, would be effective and would perhaps be the most simple method but is, unfortunately, very costly.

A possibly cheaper method might be to neutralize the settled wastes with carbon dioxide in the form of flue gas which could be bubbled through the wastes. Lime would be precipitated as calcium carbonate and, if the process were continued, sulphide would be stripped out. It would, of course, be necessary to ensure that no nuisance arose on account of the presence of hydrogen sulphide in the atmosphere. Ways of doing this are being studied.

A method, effective on a small scale, is to pass the waste gases containing hydrogen sulphide into a coke-packed filter, irrigated with a mixture of less polluting tannery wastes. Hydrogen sulphide is absorbed and oxidized by bacteria to sulphuric acid. A possible difficulty, however, is that the efficiency of the process falls off appreciably at low temperatures.

Experiments are also being made on treatment of a mixture of settled tannery wastes on a percolating filter, using a high rate of recirculation of effluent in order to reduce the alkalinity of the waste water applied. This would be an effective and convenient form of pretreatment but for the fact that chalk is deposited in the filter and might, in time, cause blockage. At a loading of 0.29 lb BOD cu/yd/day, 95 per cent of the sulphide, 80 per cent of the 5-day BOD and 60 per cent of the 4-hour permanganate value is removed.

Another important item of research during the year was the treatment of waste waters containing cyanide. Cyanides are widely used as constituents of electroplating baths for the deposition of zinc, cadmium, copper, and silver. Sodium cyanide, as the fused salt, is also used in a process for the case-hardening of steel components.

Rinsing waters from processes such as these are therefore likely to contain cyanides, both as the simple sodium cyanide, and as complex cyanides of various degrees of stability. In addition, cyanides are also present in certain liquors discharged from gas works and coke ovens.

All cyanides, apart from the most stable complex cyanides such as nickelocyanides and ferrocyanides, are extremely toxic to fish. For example, 0.2 mg/L (as HCN) of a simple cyanide will kill half a batch of rainbow trout in about 11 min. It has also been found that concentrations of about 2 mg/L have an adverse effect on sewage-treatment processes.

The concentration of cyanide in wastes containing simple cyanides and the less stable complex cyanides may be reduced sufficiently to permit discharge to a sewer by treatment with ferrous sulphate and an alkali. For wastes which demand a higher degree of purification, such as those

discharged to small rivers, treatment with chlorine and an alkali has been shown to be very effective.

Rather surprisingly, in view of the harmful effect of cyanide on sewage treatment processes, has been the possibility of treating waste waters containing simple cyanides and the less stable complex cyanides by passage through a percolating filter or by the activated-sludge process. It is possible to build up a biological film which uses the cyanide as a source of carbon.

A pilot plant using this process is at present in operation at the laboratory. It is capable of effecting almost complete removal of cyanide from a solution of sodium cyanide equivalent to 90 mg/L HCN at a rate of flow of 700 gal./cu yd/day, provided that the temperature of the effluent does not fall below 10° C. The temperature is maintained by enclosing the filter in a light shed and by electrical heating of the incoming liquid.

At present a mixture of simple cyanide and complex cyanides of zinc, copper, and cadmium is being treated. About half of the cyanide is being added as simple sodium cyanide. This mixture is much less amenable to treatment than the simple cyanide. To remove 95 per cent of the cyanide applied, it is necessary to reduce the concentration of 60 mg/L as HCN, to reduce the rate of flow to 150 gal./cu yd/day, and to adjust the pH value to 6.5.

It is thought that under certain conditions such biological processes might provide a satisfactory alternative to chemical treatment.

Oxygen Resources of Tidal Waters

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EDITOR'S NOTE: The discharge of oxygen consuming wastes to estuaries may require a knowledge of the local biological community, as well as the effect of water depth, wind, sunlight and tidal mixing. This paper describes the progress being made in learning what criteria must be observed to insure protection against oxygen resource destruction which could result from man's increased use of tidal areas.

Introduction

■ THE RAPID SUBURBAN development of many coastal areas has resulted in increasing utilization of tidal waters for both recreation and the dispersal and oxidation of organic wastes. Resolution of the conflicts which inevitably arise between these uses presents a serious problem in the management of these regions. Dissolved oxygen is doubtless the best single index of the effects of organic wastes on tidal waters, just as it is in streams. Therefore, a rational solution of these problems must depend on an understanding of the oxygen resources of tidal waters.

Recent studies of the hydrodynamics of estuaries have provided such an increase in our understanding of their circulation that it is now possible, using methods of Ketchum (1951), or Stommel (1953), to predict the distribution of an introduced pollutant. It is not yet possible, however, to predict the effects of pollutants on these regions of non-uniform environment. Mixing of fresh and salt water creates gradients in salinity and other significant properties resulting in important local differences in the rates and direction of biological processes associated with the oxidation of organic wastes. Among the most important of these local differences may be those resulting from the characteristically great variations in the abundance of plankton algae. It is also probable that there are significant differences in the exchanges of oxygen with the atmosphere caused by differences in depth, wind, and tidal mixing.

FIG. 1. BATHYMETRIC CHART of Forge River.

It is possible to estimate rates of local biological production and consumption of oxygen from relatively simple field observations. The purpose of the present paper is to use the preliminary results of an investigation of the oxygen resources of a typical polluted estuary to demonstrate the magnitude of local difference in these biological rates. Further, it will suggest how a study of such local biological processes can make possible estimates of the rates of physical processes, such as atmospheric reaeration, also involved in the maintenance of the oxygen resources of the region.

The Region

The region selected was the Forge River (Figure 1), a small estuary on the south shore of Long Island, New York. This region was chosen because it is convenient in size and location, and because at present it evidently receives from land drainage considerable enrichment. This enrichment is both organic and inorganic, with the result that there are very heavy blooms of algae during a large part of the year.

This region has been the subject of a series of intensive surveys at various times of the year. The surveys have consisted of studies of the spatial distribution of various hydrographic and biological properties, of diurnal and tidal changes in these properties, and measurements of the rates of biological production and consumption of oxygen.

The Methods

Standard procedures have been used for most of the physical and chemical measurements. Oxygen has been routinely determined by the azide modification of the Winkler method (APHA, 1955), and the absence of interfering substances confirmed by the method of Ohle (Barnes, 1959); organic matter by permanganate oxidation (Benson and Hicks, 1931); salinity by titration with silver nitrate (Barnes, 1959); and transparency with a Clarke submarine photometer.

Oxygen changes in dark bottles held at water temperature have been used to measure rates of oxygen consumption in the water. Since there are doubtless progressive alterations in the conditions in the bottles, events in the bottles may be similar to those taking place in the water only over short periods of time. In this study, rates of oxygen consumption in the water have been estimated from changes in dark bottles over periods which were as far as possible four hours or less in duration.

Oxygen consumption by the bottom-living community has been estimated by measuring changes in oxygen in darkened bell jars set on the bottom. This kind of experiment is more difficult to interpret than the more familiar dark bottle experiment. This is not only because of the inevitable disturbance of the bottom community by the presence of the bell-jar, but also because it is necessary to take account of the oxygen consumption in the water itself. In our experience the results of such experiments vary, but they nevertheless do give some estimates of the magnitude of the bottom respiration which are useful in the present connection.

Estimates of the production of oxygen by planktonic plants are difficult because the rate of photosynthesis in these plants is not a linear function of the light, being markedly inhibited by high light intensities. As a result, it is necessary to take into account not only the total amount of algae, but also its depth distribution, transparency of the water, and the daily course of solar radiation. Fortunately, Ryther and Yentsch (1957) have, as a result of their extensive studies of marine phytoplankton, been able to devise simple graphical methods by which these several variables may be taken into account. In applying these methods to this region, the depth distribution of the algae was determined by means of plant pigment assays (Richards and Thompson, 1952). The maximum rate of oxygen production by a plant pigment unit was determined by exposing to various light intensities representative samples of the population held in clear bottles. Surface solar radiation was determined from pyrheliometer records made at the Brookhaven National Laboratory, Upton, New York, and the distribution of this radiation in the water estimated from transparency measurements. It was then possible to estimate the rate of oxygen production of the population as a whole using the methods of Ryther and Yentsch. Although this procedure is somewhat involved, it has an especial advantage in that it is possible to estimate the rates of oxygen production for conditions other than those of the day of observation of the population; for example, for days of the maximum, average, or minimum radiation that might be expected during the particular period.

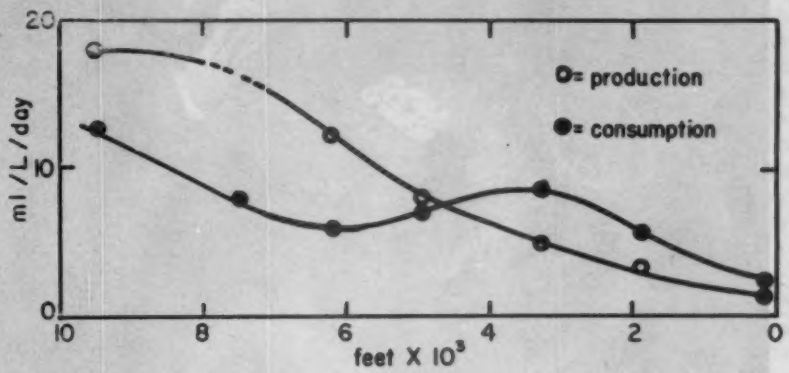

FIG. 3. RATES OF RESPIRATION and photosynthesis along land-sea axis of Forge River in September, 1959; sea at right of diagram.

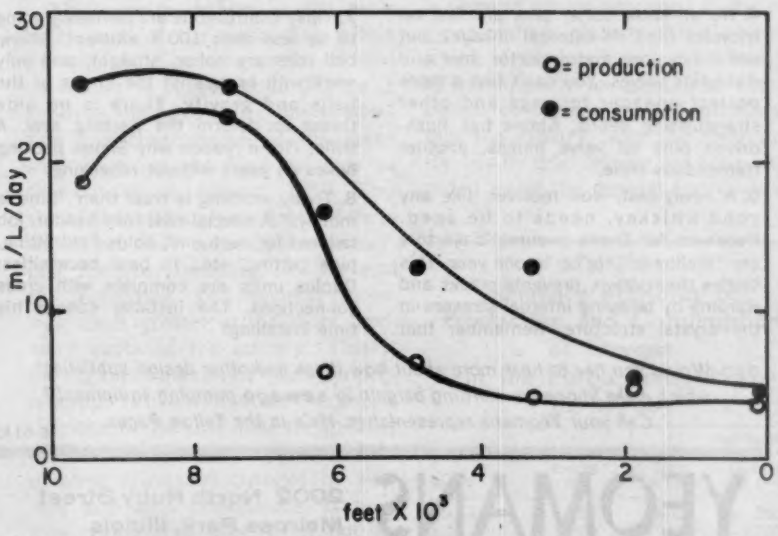

FIG. 2. RATES OF RESPIRATION and photosynthesis along land-sea axis of Forge River in August, 1959; sea at right of diagram.

These estimates of production and consumption of oxygen were generally based on observations made at about sixteen stations in the Forge River.

Results

There have been large seasonal changes in the rates of production and consumption of oxygen as shown in Table 1. There is, of course, a regular seasonal increase in photo-

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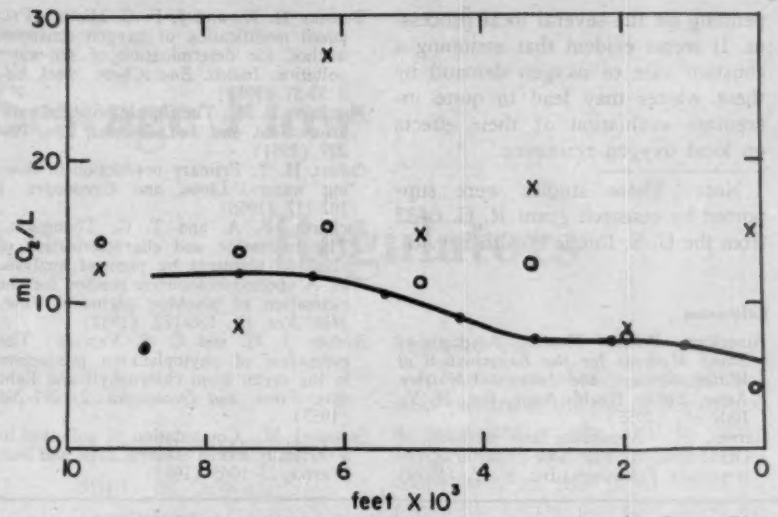

FIG. 4. COMPUTED DISTRIBUTION of organic matter in the Forge River (solid circles connected) compared with observed distribution of organic matter in August (crosses) and September (open circles).

synthetic production of oxygen to maximum recorded values in August, an increase which is clearly the result of changes both in solar radiation and amounts of photosynthetic algae. What is of more particular interest is the even greater increase in rates of oxygen consumption in the water which results in an average net oxygen consumption of as much as 600 lbs/acre/day. We cannot yet exactly establish the cause of this oxygen consumption, but the oxygen demand of the water entering from the river offers the possibility that a substantial fraction might be accounted for by the organic matter introduced in this way.

The average values in the table hide much of the variability within the region. The magnitude of this variability is suggested in Figure 2, showing the rates of oxygen production and consumption at the seven stations along the land-sea axis of the estuary in August, 1959. This shows that although everywhere there was a net daily consumption of oxygen, the daily turnover, i.e., the sum of respiration and photosynthesis, was much greater in the more landward parts of the estuary. This is the region of maximum plankton populations. It is obviously in this region that one would anticipate the greatest diurnal variations in oxygen, and the greatest effects of changes in weather and algal populations. It is in this region that short-lived but intense blooms of algae have been most obvious, although it has not been possible fully to investigate their effects on local oxygen resources.

Perhaps the most significant aspect of the observations presented in Figure 2 is the change in the ratio between respiratory oxygen consumption and photosynthetic oxygen production (R/P) along the axis of the estuary. This R/P ratio varied from almost unity in the landward portions to nearly 3 in the seaward portions in August. As shown in Figure 3 the differences in September were even more striking, the R/P ratio varying from a minimum of ½ to about 2.

A possible explanation for these differences in R/P ratio is that there is organic matter produced in the regions of high photosynthetic activity which is displaced seaward where it is subsequently oxidized. The distribution of organic matter introduced into the estuary from the river and the bay by tidal mixing has been computed using the general formulations of Stommel (1953) for the distribution of pollution in well mixed estuaries. In this computation the average observed salinity distribution and river flow in August, 1959, has been used to determine the eddy diffusivity at 1,000 foot intervals along the axis of the estuary, and the average rate of oxygen consumption in each section to determine the rate of oxidation, or half life, of the introduced organic matter. The resulting steady state distribution of this introduced organic matter is compared in Figure 4 with the organic matter present as determined from chemical oxidation. It may be seen that there seems to be more organic matter present than can be accounted for by tidal mixing. Presumably, this excess organic matter accumulates in this region as a result of the local activity of the planktonic algae.

Table I
Summary of Rates of Production and Consumption of Oxygen in the Forge River, 1959
ml/m²/day

Survey	Oxygen Production	Oxygen Consumption	Net Production (+) or Consumption (−)
March	700	500	+ 200
June	2,700	4,700	−2,000
August	7,300	12,100	−4,800
September	3,100	7,300	−4,200

One way to isolate and study these events is to observe the diurnal changes in oxygen concentration that result from diurnal changes in biological rates. In the Forge River these diurnal changes have been very large, the oxygen concentration changing from over 150% of saturation in mid-afternoon to very low values before dawn, sometimes almost zero at the surface. If the rates of the biological processes are known, it is possible to determine their part in these diurnal changes, and thence, under certain circumstances, to determine the rates of exchange with the atmosphere. Horizontal tidal movements of the water present a complication in an estuary, but it has been possible to follow the diurnal changes in essentially the same body of water in some portions of this estuary that are somewhat isolated from tidal effects. Using the method of Odum (1956) the rate of exchange of oxygen with the atmosphere has been estimated from these diurnal studies. In August and September of 1959, the exchange coefficients near the region of maximum phytoplankton activity were found to be respectively 1.68 and 1.71 gm $O_2/M_2/hr$ at 0% saturation.

Using these exchange coefficients it can be predicted that, with the rates of oxygen consumption observed in these regions at that time, the minimum nighttime oxygen concentration would approach 65% of saturation, a level that was actually observed just before dawn. With simi-

lar assumptions it would be possible to predict the minimum oxygen concentrations that would result in that region from additional oxygen demands. these predictions cannot, however, be extended to the entire estuary or to other times of the year until there is further understanding of the local processes, both biological and physical, that determine the local oxygen resources.

The significance of the difference in the accumulation of organic matter and in the production and consumption of oxygen, is that organic wastes introduced into an estuary may have quite different effects on the oxygen resources within it depending on the several local processes. It seems evident that assuming a constant rate of oxygen demand by these wastes may lead to quite inaccurate evaluation of their effects on local oxygen resources.

Note: These studies were supported by research grant R. G. 6432 from the U. S. Public Health Service.

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Sewage Flow Regulators

by MAX B. PHILLIPS
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Bryan, Ohio

■ IN THE DEVELOPMENT and extension of sewerage systems, it is and has been necessary to regulate and control flow to some portions of the systems. During storm periods or thaws, excessive flow volumes may cause considerable damage or serious inconvenience if not relieved at desirable points and times. Since many systems are extensions of original design, the problems presented are somewhat in common but may also be local in nature.

Where engineering design and study determine, some type of regulator for volume control may be used. Generally, these regulators are placed on sanitary or combined sewers, near an available outlet to a storm sewer or water course. These regulators are designed to collect the normal sewage volumes and contain some means of limiting flows that eventually reach the sewage works for treatment.

Usually, from 50 to 200 per cent over normal volumes may be admitted, and the excess bypassed or excluded to a convenient and permissable outlet. Where the sewerage system terminates in a sewage works, flows only 25 to 75 per cent over normal capacity can be treated. In the event more volume is received, it will be bypassed or only partially treated, although in many locations it may be better to control the bypass at the sewage plant than in many parts of the system, such as in parks or within congested areas.

Regulator Use

In order to obtain a broad and clear picture of the use of regulators, a questionnaire was sent to sixty Ohio villages and cities. Forty-three cooperated, so this paper could be prepared. Thirty per cent listed infiltration and storm flow a major problem; fifty-one per cent have some difficulty; and eighteen per cent have little or no trouble from storm water. Of these villages and cities, seventy-seven per cent have regulators. The numbers vary from 2 reported in Salem to the complex of 378 regulators in Cleveland.

Types of regulators used are noted as follows in decending frequency: overflow dams or weirs; flood gates; orifices; float operated gates; and leaping weirs. Malfunction is present in all types. Causes may be grease, corrosion or the inumerable objects that find their way into the sewers. Some cases were reported to be caused by poor design and adjustment. Flood gates have been a widespread problem, either by sticking open or closed.

The problem, of course, is to collect sewage flow within desirable limits and still provide a reliable means of exclusion. Regulators that permit escape of sewage into a storm sewer at other than permissible times certainly constitute a violation. So these violations may be eliminated, the regulator must be practical, efficient and require a minimum of attention. It is evident from the characteristics of sewage and industrial wastes, this a difficult matter.

Inspection and Maintenance

In the municipalities reporting, about half of the regulator systems are inspected by sewage plant personnel; the remainder by street departments or departments of public service. It is apparent that, among the villages and small to large cities, regulator inspection is within the responsibility and duties of sewage plants. In the larger cities it has been necessary to place the responsibility with the departments of public service or an allied department because of the extent of the system. Inspections have been noted on a daily, twice weekly, weekly, monthly, and quarterly basis.

It is interesting to note that only twenty per cent of the sewage plants have regulator maintenance, while eighty per cent of the maintenance work is performed by others.

In my first-hand information with the City of Bryan for the past nineteen years, regulators have been a continuous problem. In the interceptor sewer construction of 1938 and 1939, fifty orifice type intercepting manholes were constructed. Some were proposed as temporary, while others were to be permanent. Further sewer construction has eliminated only four of these regulators.

When the sewage plant was completed in January of 1940, weekly inspection of the regulators was performed by sewage plant personnel. Due to work schedules required in the plant, these duties were shifted to the Street Department in 1941. For various reasons, such inspections were returned to the sewage plant after two or three months. In the period of 1945 to 1947, there was a general breakdown of inspections and the system was neglected. However, in 1947, the sewage plant assumed such inspections and a satisfactory and efficient schedule was set up which remains to the present as a part of the sewage plant operations.

First, the necessity and requirements were presented to the governing body, so time and equipment would be provided. A report form was made up, numbering each regulator and the location. When the usual inspections are made on Monday and Friday mornings, each was noted as open or closed. By such records we have been able to determine the best size orifice for each location. At all times two men work together in this program. The date and the time of inspection is always noted, as well as by whom the work was done Since all regulators are on combine' sewers, the closures are usu lly caused from street wash or large objects that lodge in or near the orifice and then build up sludge to the point

where the mass closes the opening. Only a long pole is required to open these orifices and the sludge and accumulations is washed into the intercepting sewer.

Whenever an infrequent maintenance is required, a work request is sent to the Street Commissioner, who cooperates in cleaning and reports the materials and cost of work performed.

When pressed for time, by experience we know the regulators having strong sewage or industrial wastes and inspect these in precedence over others. It is a matter of judgment when to inspect regulators following rainfall or a thaw, and the decision may be determined by the amount of dilution available at the time.

We have a workable and agreeable program, which is continually being promoted to City Council. In general, the problem may be handled in much the same manner and as outlined as follows:

1. Provided the proper information to the governing body.
2. Determine the extent of the problem.
3. Determine the frequency of inspection.
4. Determine the responsibility for inspection and maintenance.
5. Provide the necessary tools and equipment, including record form and required safe guards.
6. Have a fairly flexible program, and make changes and adjustments where possible.
7. Submit inspection and maintenance of the regulator system as a budget item, and make frequent reports to the governing body.

Departmental friction was evident in a few cases, although this should never be permitted to approach the point where the situation will suffer. Friendly rivalry may be agreeable and can exist without damage to relations.

Regulator Administration

Sewage plant personnel should have control of the regulator system and, if this is not possible, all records of inspections and maintenance should be made available to the plant. Possibly, the extent of violations to a water course may be of little or no importance to street departments and may be beyond the knowledge of the governing body. This is a hazard to be faced and is overcome only by education and a desire of all parties to cooperate to keep violations within reasonable limits.

Actual maintenance is probably better carried out by street or allied departments, inasmuch as they have the necessary equipment and engage in this activity on a full time basis.

Records should be kept and made available in every municipality having regulators of any type, and these records should be of equal importance as the data required on the use of the sewage plant bypass as noted on the report form submitted to the State Department of Health.

It is only where complete understanding and harmony exist among departments and city officials that a satisfactory solution can be developed on this permanent and growing problem.

Excavation and Pipe Foundations
for Sewage Collection Systems

by KENT S. KASER
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William Matotan & Associates
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EDITOR'S NOTE: Good water and sewage pipe installation involves a great deal of attention given to the mechanics of construction and supervisory detail. This article serves as a review of some of the more important things to consider and of the methods that make an installation a successful one.

■ MODERN LIVING demands modern sewage collection systems, regardless of the conditions that may be encountered in the construction of these facilities. As would be expected, the problems in the sewer construction field are many and frequently complex. Correct methods of excavation and the choice of proper pipe foundations are primary factors to be considered during both design and construction of sewage collection systems. Sewers must be installed in all kinds of soil, from soft sandy soil above ground water to hard coral rock well below the water table. A thorough knowledge of the actual conditions to be encountered in any particular project is necessary to assure a well-designed and well-constructed installation that can be expected to perform its function for many years.

Soft Sandy Soil

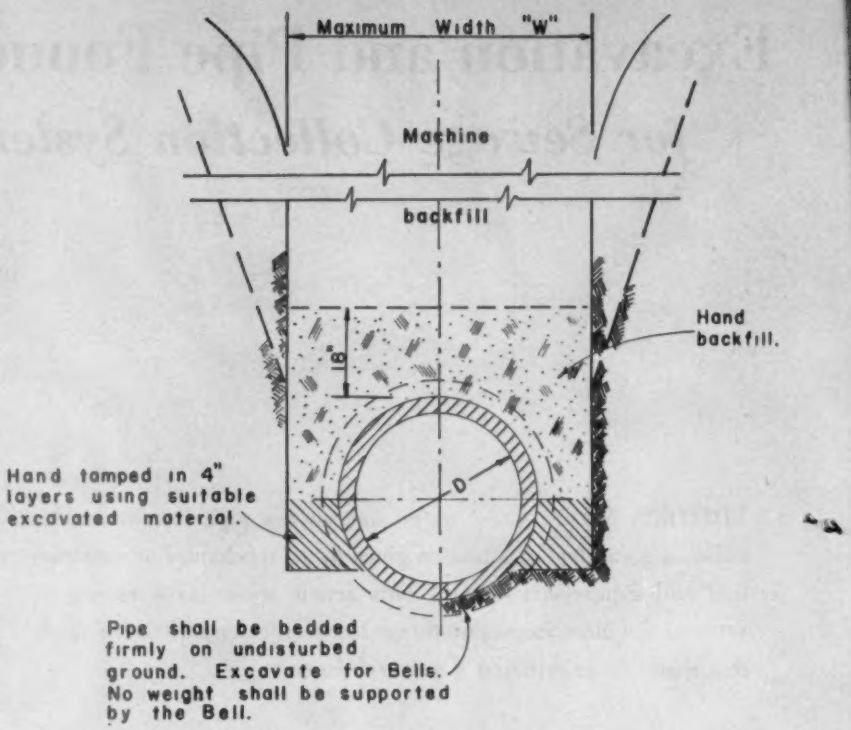
Of the various conditions encountered, probably the simplest and least costly to contend with is construction in soft, sandy soil. Excavation is easy and fast, usually being done up to depths of 22 feet with a backhoe, with draglines or clamshells taking over in deeper cuts. At normal depths, the bottom of the trench is easily shaped to fit the barrel of the pipe. Proper bedding of the pipe is not a serious problem in this type of soil, because the pipe practically beds itself. However, there can be problems here that should be of concern to the contractor as well as to the inspector on the job. The walls of the trench are subject to caving and should be watched very closely, especially when men are working in the trench. Where room is available on the surface, the trench walls may be sloped sufficiently to minimize caving. If there is not adequate room for sloping the walls, they should be sheeted or braced. Many contractors use a steel box, usually about 8 feet long, 2½ to 3 feet wide, and as high as necessary to protect the men. The box is pulled along in the trench as the work progresses. This is usually a satisfactory arrangement, but there is always a possibility that when the box is pulled forward, it may catch on the bell of the last section of pipe, disturbing that section or even pulling the joint loose. This difficulty can be overcome by holding back against the bell of the last section of pipe with a shovel or crowbar while the box is being moved.

Probably the most difficult condition to control in this type of soil is the trench width at the top of the pipe. This has considerable importance because it directly affects the loading on the pipe. Where a box is used the width can be controlled by removing the last 8, 10, or 12 inches of the excavation by hand inside the box, the actual depth to be hand excavated depending on the size of pipe to be installed. This hand work requires very little additional time in this type of soil. When sheeting is used there usually is no problem of trench width, inasmuch as the contractor, for reasons of economy, will probably maintain as narrow a trench as possible.

Backfilling should be done by hand around the bottom half of the pipe barrel and thoroughly compacted to provide a firm and uniform bed. This compaction is usually done with hand tampers; however, under certain conditions this compaction may be accomplished by means of puddling with water. Before this method is approved, tests should be made in the field to assure that proper compaction will result under actual field conditions. The backfilling should be continued by hand and thoroughly compacted to approximately 18 inches above the top of the pipe in order to assure uniform loading on the pipe and to effectively dissipate any shock load that might occur during the machine backfilling operation. The remainder of the backfill with this type of soil can usually be effectively compacted by thorough puddling or ponding with water. Figure 1 shows a typical section of a pipe installation in this type of soil.

Even when ground water is encountered it is usually not too difficult to dewater the trench by means of a simple wellpoint system. Many times a contractor will attempt to sidestep the wellpointing operation by merely pumping out the excess

water in the trench with a sump pump. There are at least three important reasons why this should not be permitted. First, it is practically impossible to keep the pipe joints clean when there is any water in the bottom of the trench. Wet sand will be trapped in the bottom of the pipe bell when the joint is made up and such a joint will eventually be a source of trouble with ground water infiltration. Second, it is usually necessary to remove the pump suction line before backfilling; this allows the water level to rise over the pipe before it is properly backfilled, and there is a good possibility that the pipe will float out of proper alignment. Third, certain joint materials are adversely affected by being allowed to become wet before they have had a chance to set up. The resident engineer or inspector on any sewer construction project should insist that, wherever possible, the pipe be laid in a dry trench, and the contractors should take this into account when preparing their bids.


Maximum Width "W"
Machine
backfill
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1/4 D
D
Hand tamped in 4" layers using suitable excavated material.
Pipe shall be bedded firmly on undisturbed ground. Excavate for Bells. No weight shall be supported by the Bell.

FIG. 1. TYPICAL SECTION showing pipe installation in soft sandy soil.

Clay Soils

Construction of sewers in clay has both advantages and disadvantages over construction in soft sand. When the clay is relatively dry, the excavation itself may be even simpler from the contractor's viewpoint than in the sandy soil previously discussed. It is usually done with either a backhoe or a trenching machine. Although trench walls may be kept practically vertical with little danger of caving, it is cheap insurance against possible injury or loss of life to brace the trench walls at regular intervals. Trenches need usually be only as wide as the bucket on the excavating machine. If a backhoe is used, the bucket width will seldom be less than 30 inches for trenches up to 10 feet in depth. When deeper cuts are encountered, a larger machine with a larger bucket is usually required.

It should be kept in mind that, due to present high labor costs, time-consuming hand work should be kept to a minimum. As a result, it is no longer realistic to require in the specifications for sewer construction in clay that the bottom of the trench be trimmed by hand to fit the barrel of the pipe, because few contractors, regardless of the inspection, will see that this is properly done. Figure 2 shows a much more practical method of construction under these conditions. The trench is excavated to approximately 4 inches below the bottom of the sewer pipe (additional depth is required when sewers exceed 15 inches in diameter). Sand or other pliable bedding material is then placed and compacted in the trench to bring it to proper grade. After the pipe has been laid, additional bedding material is placed around the pipe up to one-quarter of its outside diameter. The backfilling is again done by hand to approximately 18 inches above the pipe in a manner similar to that discussed for soft sandy soil. Although the remainder of the backfill can be suitably compacted by ponding with water, it is a much slower process than when used with sandy soil. Compaction using mechanical tampers is probably the more desirable here and it is not unreasonable to require a contractor to use this method because the trench widths are narrow and the volume to be compacted is minimal. If the ponding method of compaction is used, a close check of the pipe loading should be made, inasmuch as the overburden will be heavy saturated clay with a low friction coefficient. These conditions result in an exceptionally heavy loading on the pipe.

Probably one of the worst conditions to be encountered in the installation of sewers is soft wet clay. When this is encountered the contractor is faced with caving trench walls, difficult dewatering, unstable foundation conditions, and unpleasant working conditions for the men. Because it is very difficult to lower the water table by means of well-pointing, the contractor is faced with sloughing or caving of the trench walls. This can be controlled by some method of sheeting. In cases where extreme conditions are encountered, solid sheeting will be required. This is a costly and time-consuming operation, but it is necessary to maintain allowable trench widths and to provide the necessary safety measures for the men in the trench.

The sewer pipe foundation must be prepared so that unequal settlement will be held to a minimum. Figures 3 and 4 show methods of installation where sheeting is not required. Figure 5 shows the method of construction where solid sheeting is used. Whether the method used should correspond to Figure 3, 4, or 5, or even possibly some other method, will depend on the conditions encountered. Regardless of which method is used it will probably be

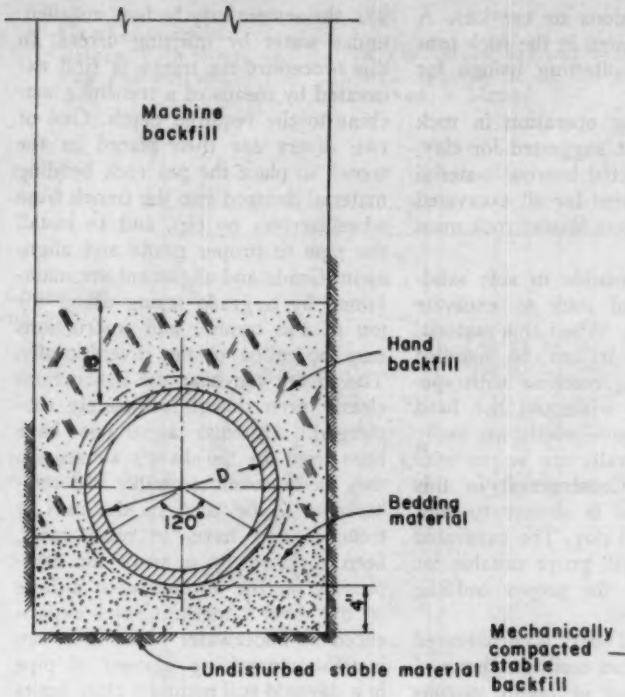


FIG. 2. TYPICAL SECTION showing pipe installation in extra hard clay.

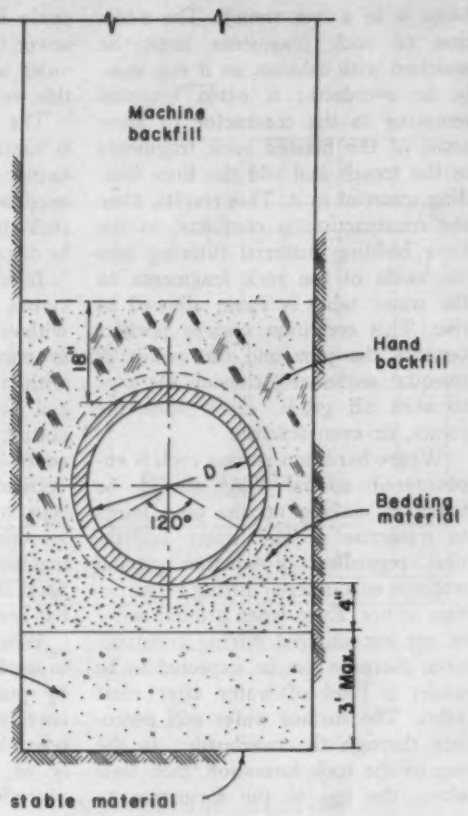


FIG. 3. TYPICAL SECTION showing pipe installation in soft clay.

necessary to remove some of the unstable material from the trench and replace it with crushed rock, concrete cradle, or some other stable material. The method of backfill is the same as for a dry trench, but it may be necessary to backfill with borrow material, in which case the excess unsuitable excavated material must be disposed of.

Rock

Although costly, the construction of sewers in rock has certain definite advantages over construction in other types of soil. Trench walls can be held vertical with no fear of caving and, if the blasting crews are experienced, trench widths can be closely controlled. The trench should be excavated to a depth of 4 to 12 inches below the outside bottom of the pipe, depending on the size of pipe to be installed, and all rock fragments should be removed. Special care should be taken to see that no high spots remain in the trench bottom, as a high spot could easily cause a pipe failure. Table 1 gives bedding and trench width requirements that have been proved satisfactory for various sizes of pipe. Also given is the quantity of bedding material per linear foot of pipe based on the depth of bedding and the allowable trench widths indicated.

The bedding material should be similar to that described for clay trenches. It should be granular sand, sandy gravel, or pea rock, and should allow rapid transmission of ground water through the voids. When ground water is encountered it may be removed by means of a sump pump, because wellpointing is usually impossible. At any rate, the trench should be maintained as dry as possible. It may be desirable to add some of the smaller blasted rock fragments to the bedding material to help sta-

Table 1
Allowable Trench Widths and Required Bedding Material for Sewer Construction in Rock Trench

Inside Pipe Dia., in.	Width of Rock Trench, ft-in.	Depth of Bed,[a] in.	Pipe Bedding,[b] cu ft
10	2-1	4	1.1
12	2-4	4	1.3
15	2-8	4	1.8
18	3-0	6	2.7
24	3-8	6	3.9
30	4-4	8	5.7
36	5-0	8	6.9
42	5-8	8	9.0
48	6-4	8	10.7
54	7-0	8	13.7
60	7-8	8	14.8

[a] Below outside bottom of pipe.
[b] Cubic feet per lineal feet of trench, based on bedding material around bottom third of pipe.

bilize it in a wet trench. The addition of rock fragments must be watched with caution, as it can easily be overdone; it often becomes tempting to the contractor to leave some of the blasted rock fragments in the trench and add the finer bedding material to it. This results, after the construction is complete, in the finer bedding material filtering into the voids of the rock fragments as the water table is again allowed to rise. This condition creates pockets beneath the pipe and can result in unequal settlement, causing the pipe to shift off grade, crack open the joints, or even fracture.

Where hard non-porous rock is encountered special care should be taken in making up the pipe joints to minimize ground water infiltration, regardless of whether ground water is encountered during construction or not. Even when ground water is not encountered during construction, the pipe can be expected to be under a head of water after most rains. The surface water will percolate through the overburden to the top of the rock formation, then flow along the top of the formation to settle in depressions or crevices. A sewer trench blasted in the rock provides an ideal collecting trough for this water.

The backfilling operation in rock is similar to that suggested for clay, except that selected borrow material must be substituted for all excavated rock and the excess blasted rock must be disposed of.

It often is possible in soft sandstones and coral rock to excavate without blasting. When this material is encountered it can be handled with a trenching machine with special buckets to withstand the hard cutting. Here again, widths are easily controlled and walls can be cut with vertical faces. Construction in this type of material is similar to construction in hard clay. The excavated material often will prove suitable for backfilling after the proper bedding has been provided.

Where ground water is encountered in sandstone it can easily be removed by pumping, but in highly porous coral rock it may be practically impossible to lower the water sufficiently to utilize standard construction procedures. When this condition occurs, the sewers may be best installed under water by utilizing divers. In this procedure the trench is first excavated by means of a trenching machine to the required depth. One or two divers are then placed in the trench to place the pea rock bedding material dumped into the trench from wheelbarrows on top, and to install the pipe to proper grade and alignment. Grade and alignment are maintained by a grade string along the top of the trench, and instructions may be called to the divers orally. The divers can hear the instructions clearly even though completely submerged. Although aqualungs have been tried for the diver's air supply, they have proven too bulky and cumbersome to be used in the narrow trenches and have, in most cases, been replaced by a small air compressor on the surface with a hose to the diver's mask. Crews experienced in underwater installation can install a surprising amount of pipe in a day and still maintain close limits on grade and alignment. In coral rock the excavated material is usually used for the backfilling operation; because most of the backfilling is

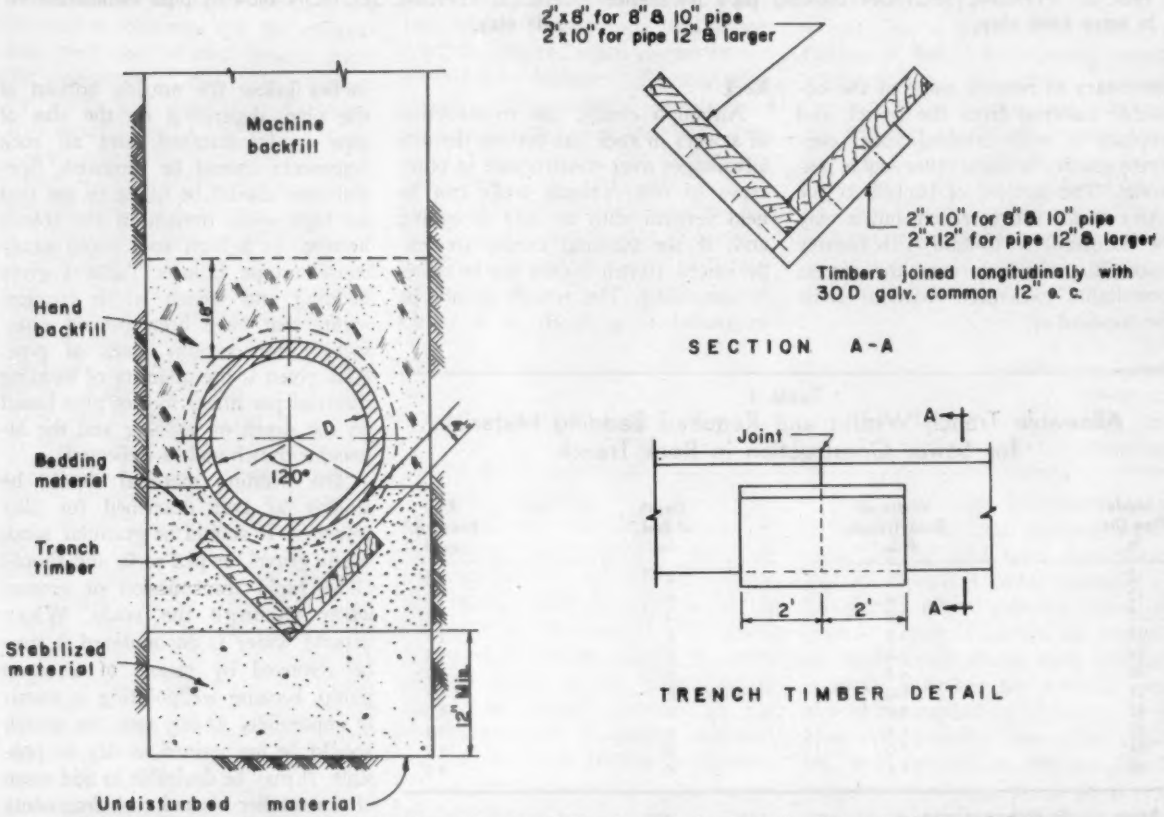


FIG. 4. TYPICAL SECTION showing pipe installation in soft clay trench with unstable trench bottom.

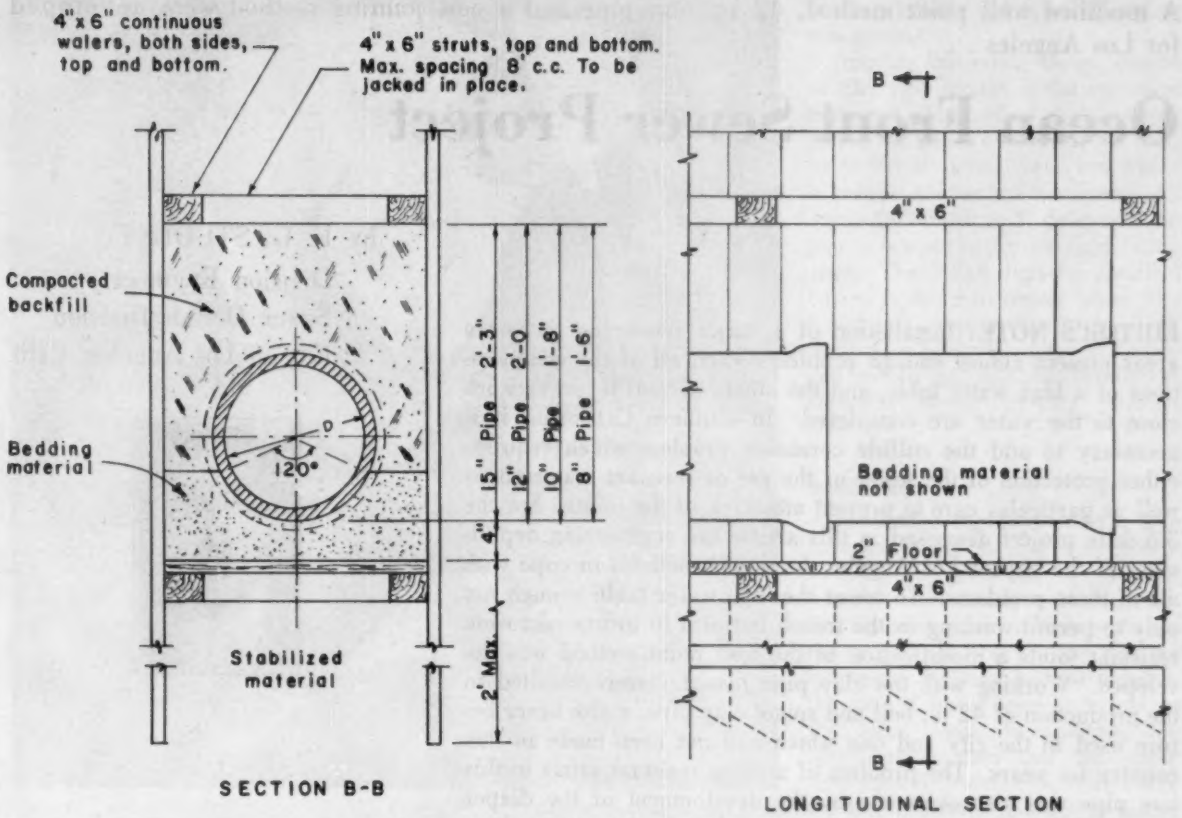


FIG. 5. TYPICAL SECTION showing pipe installation in extremely unstable soil, using solid sheeting and plank trench floor.

done under water, it is common practice to provide no compaction other than mounding up the top of the fill in the trench to allow for some slight settlement, and then allowing construction equipment to run over it at random.

Conclusions

The fields of engineering and construction have always provided a challenge for man's ingenuity and imagination. The design and construction of sewage collection systems has been no exception. Haste indeed makes waste in the design and construction of sewage collection systems. The designer who fails to make every possible effort to determine the conditions under which his particular facilities are to be installed will most certainly be faced with many unnecessary problems during construction. The contractor, on the other hand, who attempts to cut corners during construction of the facilities will undoubtedly find himself in serious difficulty and may be faced with the expense of reconstructing portions of his work. The many varied conditions that may be encountered in sewer construction work makes a thorough knowledge of engineering principles and construction procedures necessary for good economical design.

Reference

1. *Eng. News-Rec.*, Oct. 17, 1957, p. 230.

A modified well point method, 42 in. clay pipe and a new jointing method were developed for Los Angeles . . .

Ocean Front Sewer Project

by E. G. STUDLEY
Division Engineer
Sewer Design Division
City of Los Angeles, Calif

EDITOR'S NOTE: Installation of a major sewer line in ocean areas present almost enough problems when all of the complications of a high water table, and the others normal to sewer work close to the water are considered. In southern California it is necessary to add the sulfide corrosion problem which requires either protection of the sewer or the use of resistant materials as well as particular care to prevent attacking of the joints. For the 3.5 mile project discussed in this article the engineering department of the city of Los Angeles developed methods to cope with all of these problems. To lower the high water table enough not only to permit working in the trench but also to insure corrosion resistant joints a modification of the well point method was developed. Working with the clay pipe manufacturers resulted in the production of 42 in. bell and spigot clay pipe, a size never before used in the city and one which had not been made in this country for years. The problem of making resistant joints in this size pipe was also overcome by the development of the diaper joint method. These methods will be of definite interest to those engaged in this type of work.

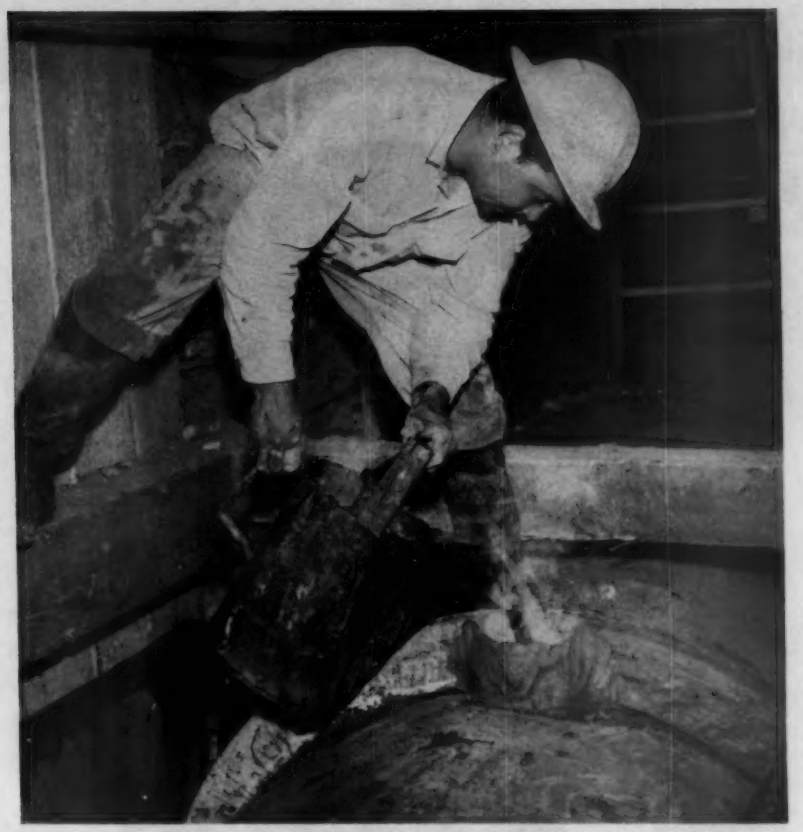
■ INSTALLATION OF AN OCEAN front sanitary sewer system such as the one now being installed in the City of Los Angeles area, poses a multiplicity of problems to the design engineer, the contractor and the pipe manufacturer. In this particular case, the solution of these problems has led to several new developments in sewer installations including the first use on the west coast of 42 in. diameter bell and spigot clay pipe.

The Los Angeles installation is a $3,960,000 sewer project consisting of gravity lines, a pumping station and an extensive force main to serve the ocean front area of Venice, the City of Santa Monica and areas tributary thereto. This sewer will extend from the southern boundary of Santa Monica to the outfall sewer at Playa del Rey—a distance of almost 3.5 miles. The new sewer became necessary when the existing system had to be abandoned to make way for the new small boat harbor at Marina Del Rey.

Financing of the Los Angeles project was provided by agreements

Courtesy of Gladding, McBean & Co.

FIG. 1. THE INSTALLATION OF THE WELL POINTS in the 7 ft cut as shown here permitted lowering of the water level to a maximum of 25 ft.



Courtesy of Gladding, McBean & Co.

FIG. 2. HOT SEWER JOINT COMPOUND being poured into the clay pouring gate of a diaper formed joint.

entered into by the Cities of Los Angeles and Santa Monica and the County of Los Angeles. By these agreements, the City of Los Angeles is appropriating $1,838,000, the City of Santa Monica $1,222,000 and the County of Los Angeles $900,000. Money for these appropriations came from bond issues approved for sewer projects in the Cities of Los Angeles and Santa Monica and from revenue bonds, which will be sold by the county. Pending the sale of these bonds, the city advanced the county's share.

Corrosion

The history of large sewers serving the city of Los Angeles has been one of corrosion and continual expense to combat this corrosion. The excessive corrosive conditions are caused by the large amounts of hydrogen sulfide generated in the lines. When these sulfide gases oxidize to sulfuric acid, they attack unprotected concrete surfaces. Under these conditions the present design practice of the city specified that clay pipe is to be used wherever available in the required diameter. Whenever clay pipe is not available, the inner surfaces of concrete sewers above the low flow line must have protective lining.

On the basis of the city's good experience with clay pipe up to 39 in. in diameter, and with several projects in the offing requiring a larger diameter, and with several projects in the offering requiring a larger diameter pipe, the City Engineer asked the clay pipe manufacturers if they could make a 42 in. diameter clay pipe. In addition, since the corrosive conditions would require that the joints also be corrosive resistant and still permit flexibility, the city required the pipe to be made with bell and spigot joints. None of this size and type pipe had been made in this country in recent years and it never had any of it been installed on the west coast. However, ceramic technicians solved the manufacturing problems and, as a result, 42 in. diameter vitrified clay pipe with a bell and spigot is now available and is being used on this project.

Another interesting design feature of clay pipe section is the curves at each end. The radius at the upper end of the line is 61 ft while the radius is 100 ft at the lower end where it enters the new interceptor. All joints are limited to 5° deflection and pipe is beveled to provide tight fitting joints. The design engineers specified curves in order to reduce water turbulence at junction structures. This, in turn, reduces the release of hydrogen sulfide gas and the subsequent corrosive effects on the junction structure.

Installation

The design engineers and the pipe manufacturer having successfully solved their problems, the product was now turned over to the contractor. The magnitude of their problems can be realized from the fact that the interceptor is being laid 20 ft below the ground water level and close to the ocean front. In addition, the specifications state that the water level must be lowered two feet below the trench bottom in order to insure obtaining the best possible hot-pour joint. Further complicating one contractor's job were several thousand feet of his part of the interceptor which are located in the middle of the Venice Grand Canal.

In studying the de-watering problem, it was evident that use of a well point system installed at the surface level would not work since the maximum practical draw down of the well point system is 17 to 18 ft. This problem was solved by making an initial cut of 7 ft, and installing the well point system at that level, which permitted lowering of the water level to a maximum of 25 ft below ground surface. Diaphragm pumps were also used in selected locations to assist the well points in completing the dewatering.

Once the water level was lowered, trenching could begin. Instead of making the usual V-cut in an installation of this kind, thereby losing most of the street, one contractor used a backhoe with a shield attachment. The trench was held open while solid sheeting was installed with pneumatic rams. This method, which made possible a narrow trench, led to a mini-

mum of interference with traffic on a busy thoroughfare.

Jointing

For laying the clay pipe line, a new method of retaining the hot-pour compound in the annular space was developed. Instead of the traditional running rope, a piece of sail cloth about 8 in. wide and long enough to go around the circumference of the pipe is used. A pocket is sewn on each longitudinal edge of the cloth, and steel straps are threaded through these seams. The cloth is then wrapped around the pipe with one edge going around the bell and the other edge around the adjacent spigot. The steel bands are drawn up tight with conventional strapping equipment, and a small gap is left between the ends of the cloth at the top of the pipe. A clay pouring gate is then formed in the regular manner at the opening, and the hot compound is poured in. These so-called "diapers" are then left in place and considered expendable.

This method is working satisfactorily and is considerably cheaper, as the materials are relatively inexpensive and a great deal of time is saved over the laborious task of installing asbestos running ropes on large diameter pipe. The contractor has also discovered that the sail cloth "diaper" allows entrapped air to escape through the pores of the material. This eliminates possible porosity due to entrained air. Another advantage of this method is the tension which builds up and assists in overcoming shrinkage of the hot pour material as it cools.

The Venice installation is an excellent example of the value of tackling each sewer design as a special problem rather than using stereotyped solutions. Sewer design engineers can, by progressive engineering thinking based on sound principles, originate new developments to overcome specific job problems. The 42 in. clay pipe was developed by Gladding, McBean and Co. The so-called diaper jointing method is the work of Drommond & Bronneck and the Hubbard Co.

Courtesy of Gladding, McBean & Co.

FIG. 3. 42 IN. BELL AND SPIGOT CLAY PIPE resting on blocks in preparation for construction of the concrete cradle.

Because they can suffer serious damage, it is imperative to provide positive . . .

Protection of Concrete Sewers
In the Presence of Hydrogen Sulfide

by RICHARD POMEROY,
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Pasadena, Calif.

EDITOR'S NOTE: Hydrogen sulfide, present in some sewage in high enough concentration to cause trouble, may pass into the sewer atmosphere and be oxidized on the walls to sulfuric acid, attacking the concrete of the walls. Concrete sewers, therefore, need protection against the acid corrosion. Proper design and operation of sewer systems to eliminate sulfide is of major importance, but the steps indicated in this article may reduce the attack considerably, even when some sulfide still remains.

■ CONCRETE SEWERS are likely to suffer serious damage when they are made to carry sewage containing high concentrations of dissolved sulfide. Some of the hydrogen sulfide, which is present as a part of the dissolved sulfide mixture, passes from the stream into the sewer atmosphere. Then on exposed walls it is oxidized to sulfuric acid, attacking concrete.

Concrete is, nevertheless, the principal construction material for large sewers. In the smaller sizes (generally 36 in. and smaller), it is in competition with vitrified clay pipe. Clay pipe has the advantage that it is not damaged by acid. But the range of conditions under which concrete pipe can be safely used, coupled with its generally lower cost, favor rather wide use in these smaller sizes also.

There are numerous methods, each with its appropriate field of usefulness, for dealing with the sulfide problem. Proper design and operation of sewer systems to eliminate sulfide is of major importance. The limited subject of this article, however, is a review of methods to increase the resistance of concrete pipe against the attack that may result where hydrogen sulfide is present.

Acid-Resistant Barrier on Surface

One approach to the problem is to protect the concrete surface with an acid-resistant barrier. This is difficult, as the protection must reach a high degree of perfection and must have a very long life.

Perfection of the coating is necessary because even one pinhole in 1,000 sq ft might be serious. If sulfide conditions are so bad that protection of this sort is necessary, the presence of an almost-perfect coating leads to deeper penetration than no coating at all. Acid formed on a non-reactive pipe wall will slowly flow down the surface and serve as a supply for rapid attack wherever a flaw exists. In one extreme case, an imperfect lining has resulted in many cavities penetrating all or nearly all of a 5-in. pipe wall in twelve years. It is estimated that the attack would have been only 1 to 2 in. if no lining had been present.

The coating must be able to resist, for a long period of time, exposure to quite high acid concentrations. The acid concentrations generally are not very high on a concrete surface, because the acid can react with the concrete. On an unreactive surface the concentrations are higher. Condensate removed from a clay surface in a junction chamber showed 7% sulfuric acid, the pH being 0.2. Microscopic examinations showed the liquid to be teeming with motile bacteria, presumably of the genus *Thiobacillus*.

Whether *Thiobacilli* can oxidize hydrogen sulfide to sulfuric acid at still higher concentrations has not been determined, but higher concentrations are found, possibly because of evaporation of condensed moisture when the sewage seasonally becomes colder than the walls of the sewer.

When conditions become unfavorable for formation of sulfuric acid, whether because of high acidity, dryness, or other reasons, there may be an accumulation of sulfur as an intermediate oxidation product. In one sewer some sulfur was scraped off the crown of the sewer in February. It contained very little moisture, but that which was present was about 25% sulfuric acid, with a pH of —0.3. The amount of sulfuric acid present was 1 lb per 60 sq ft. Linings will seldom be subjected to the effect of much acid at this concentration for any considerable length of time, but the lining must nevertheless be able to resist chemical alteration under these conditions.

The material must also remain unaltered in the presence of greases, solvents, and solvent vapors in the sewer.

The following principal types of protective barriers have been suggested or used:

1. *Materials that are hot-poured or that harden by evaporation of a solvent.* Many materials in this class have been tried, but none have been found to be effective. Some are not themselves altered, but permit diffu-

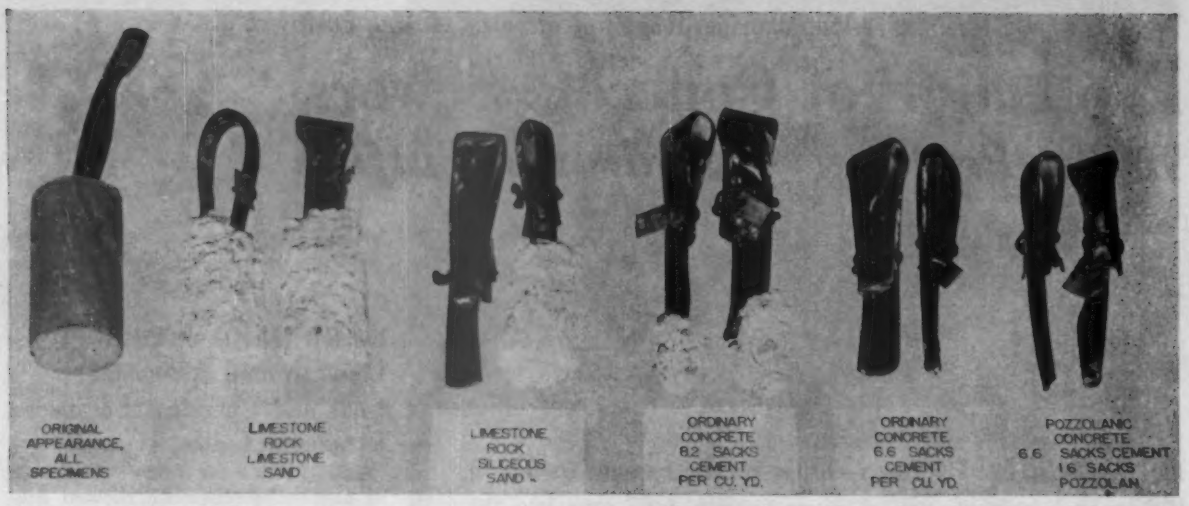
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FIG. 1. CORROSION of concrete specimens in hydrogen sulfide atmosphere of Norfolk, Va., sewer manhole.

sion of acid through them. Among painted coatings, the best showing has been made by a plastic-base paint. When applied in thick layers it may remain intact for a number of years, and probably for a very long time if no hydrogen sulfide is present. In a test installation where sulfide conditions are bad, considerable deterioration of concrete behind the coating was noted within three years. This coating may have some utility in manholes and other structures under some conditions, but could not be considered for protection of the inside of a sewer.

2. *A material that hardens by chemical reaction after being spread or sprayed on the surface.* One material of this class shows some hope of being effective. It appears to be impermeable, as judged by tests over a period of a few months. It seems likely that it will be durable. The principal question yet to be answered is whether it can be applied so that there will be no flaws and so that it will not develop any cracks, particularly if there is any deformation of the concrete structure, or motion at the joints.

3. *Liner plates.* Clay liner plates have been considerably used, and glass plates have been proposed. The clay products manufacturers have made ingenious advances in attempting to overcome problems of jointing and of permeability of the plates. Another problem is rigidity of the plates. A lined sewer has been observed where the concrete pipe showed no readily measurable deformation, but plates at the sides showed pressure cracks and shear cracks.

It is regrettable that it has been so difficult to adapt so sound a material as vitrified clay to this use, and it is hoped that success may yet be attained. As it stands now, clay liner plates in all installations where high hydrogen sulfide concentrations have prevailed have, within a few years, cracked, spalled, or fallen off in great numbers. Plates have remained intact in some locations, but only where there is little or no hydrogen sulfide.

4. *Plastic sheet.* A plastic polyvinyl chloride sheet, sold as "Amerplate," is the most successful of lining materials attempted up to this time. It undergoes some alteration in the form of loss of plasticizer and absorption of water (up to 8%), but it remains impermeable to acid so far as is known. There is some wrinkling due to expansion under some conditions, and it may tear under heavy stresses, but these are not problems of much importance. The final proof of long life of any material of this sort is obtained only after a number of installations have been in for a long time. There is a pumping station installation which has been in for 13 years, and the oldest sewer installation has been in for nine years. Thus long life has not been proved, yet the behavior of the existing installations seems to warrant the conclusion that one may safely count on a life of 25 years, with good probability of a life of 50 years. A life measured in centuries seems improbable.

Impregnation of the Concrete

Many times, over a period of years, the idea has been brought forward that pores in the concrete might be filled by forcing wax, tar, or some other material into them under pressure, and that this might increase resistance to acid attack. But the problem is not one of acid penetration through the pores; it is acid dissolution of the cement. No such attempted impregnation has been successful in providing protection from acid.

The point is well stated by Suskin (4, p. 186): "Sulfuric acid as such does not and, in fact, cannot penetrate into normal concrete because of the latter's considerable reserve of basic constituents. Acid attack therefore takes place at the surface, the latter receding as solution of the basic material (cement, etc.) takes place."

Vulnerability of porous concrete to attack by sulfate and by leaching might be offset by impregnation, but if a concrete is dense to start with, it is doubtful that this procedure would be of much benefit.

Alteration of Concrete Composition

The relationship of concrete technology to acid susceptibility has been most extensively studied in South Africa, leading to several publications, notably by Stutterheim and Van Aardt (1, 2, 3) and by the

South African Council for Scientific and Industrial Research (4). The latter reference is a book covering many phases of the sulfide problem. Part III, under the authorship of R. Suskin, deals with concrete technology.

In the researches reported by Van Aardt and by Suskin, the test specimens normally were mortar bars of 1 x 1 in. cross-section, having a cement : sand ratio of 1 :3. These were generally immersed in baths of 1% sulfuric acid renewed weekly. Modulus of elasticity, weight loss, and expansion were measured. Principal findings were :

1. A specimen prepared with a water : cement ratio of 0.60 failed much more rapidly than specimens with ratios of 0.35 and 0.45.

2. The poorest method of curing was under water. Long curing in moist air was much better. Steam curing at 95°C for 4 hrs was of moderate benefit. Curing at 75- to 180-psi steam pressure imparted substantially better acid resistance, with specimens lasting about 50% longer than those cured in air. Curing in carbon dioxide was also decidedly beneficial.

3. Increasing the proportion of cement increased the life, roughly in proportion to the cement content, over a range of cement, sand ratios between 1 :2 and 1 :6.

4. There was, in general, an increasing resistance to attack with decreasing tricalcium aluminate content. With 12% C_3A the life of water-cured specimens was about 7 weeks; with 7% C_3A it was increased to about 22 weeks.

5. High alumina cement, blast furnace slag cement, and super-sulfated slag cement were not consistently more resistant than ordinary cement, although super-sulfated slag cement was superior in some cases.

6. Substitution of part of the cement by flyash, underburned kaolin, or a pozzolan did not produce any distinct improvement in acid resistance. The effect of reduction of the proportion of cement, normally decreasing the life, apparently was offset. Addition of these materials without reduction of cement content might be slightly beneficial. Workers elsewhere have in some cases reported more distinct benefits of pozzolans in experiments of this sort. There may be differences in experimental conditions, differences in the pozzolans, and differences in the base of comparison; that is, the quality of the non-pozzolanic comparison specimens.

7. Use of dolomite or limestone for aggregate had the most marked effect in lengthening the life. In comparison with an average life, until break-up, of 35 weeks for comparable specimens with non-calcareous aggregate, one specimen made with dolomite lasted 90 weeks; another lasted 120 weeks. Two others had not broken up at 80 to 90 weeks, but had lost most of their weight. A specimen made with limestone had not broken up at 90 weeks, and had lost only about 25% of its weight and 20% of its modulus of elasticity. By extrapolation it would appear that it might last 180 weeks or longer.

8. A change in the grading of the sand showed no significant effect.

9. An increase in the length of time of spinning of concrete pipe beyond the normal time did not have any significant effect upon the acid-resistance of prisms cut from the pipe wall. Also, there was no significant difference in resistance between prisms from spun and from pressure-compacted pipe.

10. Attempts to prevent the growth of *Thiobacilli*, and hence the oxidation of H_2S to sulfuric acid, by incorporating toxic substances into the concrete, did not give promising results.

Hansen, Vellines and Brandvold (5) in the United States made experiments with Type I cement (12.7% C_3A), Type II cement (8.5% C_3A), and super sulfated blast-furnace slag cement. Cylinders of 2 x 4 in. size were immersed in 0.055N sulfuric acid (0.27%).

A cylinder made with Type I cement broke up at 47 weeks with clear evidence of sulfate attack. The other two did not show evidence of sulfate attack and lasted much longer. In an exposure regime in which specimens were immersed, each week, for three days in acid, 3 days in water, and one day in warm air, all three compositions showed similar slow attack. Pipe specimens, 6 x 12 in., made with these three compositions all showed similar attack. The water-cement ratio used in making the cylinders was 0.47; in making the pipes it was 0.30.

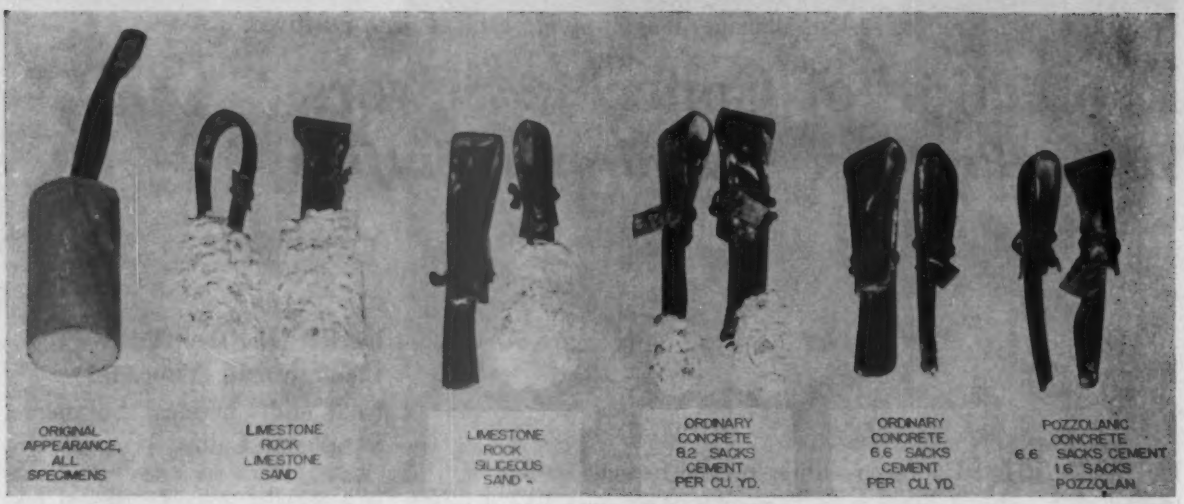
The attack of concrete by sulfuric acid can be considered to be due essentially to hydrogen ion, but it is evident that sulfate ion may also have an effect. Among the variables tested in the South African work, several were related to resistance of the concrete to sulfate attack, expecially Items 1, 2 and 4. Susceptibility to sulfate attack clearly shortened the life. The work of Hansen, Vellines and Brandvold (5) also disclosed similar effects of sulfate ion.

From all of the results it would appear that sulfate resistance can be attained by use of a low water-cement ratio, or use of Type II instead of Type I cement, or long curing in moist air. It is also clear that a high degree of resistance to sulfate attack will not prevent concrete from being destroyed by the hydrogen ions of the acid.

All of the foregoing tests were accelerated laboratory tests, under conditions quite different from those found in sewers. In the laboratory, the concrete is exposed to a virtually unlimited reservoir of acid. In the sewer, acid is formed on the walls very slowly. That which forms must either react or flow down the walls into the sewage stream. In pipes that have suffered rapid attack, one may find evidence that acid has streamed down the walls, as shown by grooves. Where the attack has been slow, one usually finds a softened layer over the interior of the pipe, perhaps varying in thickness between soffit and water line, but otherwise fairly uniform, without evidence of flow of acid.

A substantial relative increase in durability of the concrete is of minor interest if the pipe will fail in five or ten years anyway. Chief interest in modification of the concrete is for those places where this may extend the life from, for instance, 25 years to 100 years. These are the places where substantially all of the acid may react regardless of variations of concrete composition. Therefore, caution must be used in interpreting results of the laboratory experiments in terms of long years of life of sewer pipe.

The effect of calcareous aggregate, first advocated by Stutterheim and Van Aardt (1), is especially significant. There is every reason to suppose that the beneficial effect of calcareous aggregate on durability of concrete will be at least as pro-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In the researches reported by Van Aardt and by Suskin, the test specimens normally were mortar bars of 1 x 1 in. cross-section, having a cement: sand ratio of 1:3. These were generally immersed in baths of 1% sulfuric acid renewed weekly. Modulus of elasticity, weight loss, and expansion were measured. Principal findings were:

1. A specimen prepared with a water: cement ratio of 0.60 failed much more rapidly than specimens with ratios of 0.35 and 0.45.

2. The poorest method of curing was under water. Long curing in moist air was much better. Steam curing at 95°C for 4 hrs was of moderate benefit. Curing at 75- to 180-psi steam pressure imparted substantially better acid resistance, with specimens lasting about 50% longer than those cured in air. Curing in carbon dioxide was also decidedly beneficial.

3. Increasing the proportion of cement increased the life, roughly in proportion to the cement content, over a range of cement, sand ratios between 1:2 and 1:6.

4. There was, in general, an increasing resistance to attack with decreasing tricalcium aluminate content. With 12% C_3A the life of water-cured specimens was about 7 weeks; with 7% C_3A it was increased to about 22 weeks.

5. High alumina cement, blast furnace slag cement, and super-sulfated slag cement were not consistently more resistant than ordinary cement, although super-sulfated slag cement was superior in some cases.

6. Substitution of part of the cement by flyash, underburned kaolin, or a pozzolan did not produce any distinct improvement in acid resistance. The effect of reduction of the proportion of cement, normally decreasing the life, apparently was offset. Addition of these materials without reduction of cement content might be slightly beneficial. Workers elsewhere have in some cases reported more distinct benefits of pozzolans in experiments of this sort. There may be differences in experimental conditions, differences in the pozzolans, and differences in the base of comparison; that is, the quality of the non-pozzolanic comparison specimens.

7. Use of dolomite or limestone for aggregate had the most marked effect in lengthening the life. In comparison with an average life, until break-up, of 35 weeks for comparable specimens with non-calcareous aggregate, one specimen made with dolomite lasted 90 weeks; another lasted 120 weeks. Two others had not broken up at 80 to 90 weeks, but had lost most of their weight. A specimen made with limestone had not broken up at 90 weeks, and had lost only about 25% of its weight and 20% of its modulus of elasticity. By extrapolation it would appear that it might last 180 weeks or longer.

8. A change in the grading of the sand showed no significant effect.

9. An increase in the length of time of spinning of concrete pipe beyond the normal time did not have any significant effect upon the acid-resistance of prisms cut from the pipe wall. Also, there was no significant difference in resistance between prisms from spun and from pressure-compacted pipe.

10. Attempts to prevent the growth of *Thiobacilli*, and hence the oxidation of H_2S to sulfuric acid, by incorporating toxic substances into the concrete, did not give promising results.

Hansen, Vellines and Brandvold (5) in the United States made experiments with Type I cement (12.7% C_3A), Type II cement (8.5% C_3A), and super sulfated blast-furnace slag cement. Cylinders of 2 x 4 in. size were immersed in 0.055N sulfuric acid (0.27%).

A cylinder made with Type I cement broke up at 47 weeks with clear evidence of sulfate attack. The other two did not show evidence of sulfate attack and lasted much longer. In an exposure regime in which specimens were immersed, each week, for three days in acid, 3 days in water, and one day in warm air, all three compositions showed similar slow attack. Pipe specimens, 6 x 12 in., made with these three compositions all showed similar attack. The water-cement ratio used in making the cylinders was 0.47; in making the pipes it was 0.30.

The attack of concrete by sulfuric acid can be considered to be due essentially to hydrogen ion, but it is evident that sulfate ion may also have an effect. Among the variables tested in the South African work, several were related to resistance of the concrete to sulfate attack, expecially Items 1, 2 and 4. Susceptibility to sulfate attack clearly shortened the life. The work of Hansen, Vellines and Brandvold (5) also disclosed similar effects of sulfate ion.

From all of the results it would appear that sulfate resistance can be attained by use of a low water-cement ratio, or use of Type II instead of Type I cement, or long curing in moist air. It is also clear that a high degree of resistance to sulfate attack will not prevent concrete from being destroyed by the hydrogen ions of the acid.

All of the foregoing tests were accelerated laboratory tests, under conditions quite different from those found in sewers. In the laboratory, the concrete is exposed to a virtually unlimited reservoir of acid. In the sewer, acid is formed on the walls very slowly. That which forms must either react or flow down the walls into the sewage stream. In pipes that have suffered rapid attack, one may find evidence that acid has streamed down the walls, as shown by grooves. Where the attack has been slow, one usually finds a softened layer over the interior of the pipe, perhaps varying in thickness between soffit and water line, but otherwise fairly uniform, without evidence of flow of acid.

A substantial relative increase in durability of the concrete is of minor interest if the pipe will fail in five or ten years anyway. Chief interest in modification of the concrete is for those places where this may extend the life from, for instance, 25 years to 100 years. These are the places where substantially all of the acid may react regardless of variations of concrete composition. Therefore, caution must be used in interpreting results of the laboratory experiments in terms of long years of life of sewer pipe.

The effect of calcareous aggregate, first advocated by Stutterheim and Van Aardt (1), is especially significant. There is every reason to suppose that the beneficial effect of calcareous aggregate on durability of concrete will be at least as pro-

nounced for a sewer pipe carrying moderate sulfide concentrations as for the bars immersed in acid in the laboratory. Use of calcareous aggregate will not change the rate of reaction of acid on the sewer wall, because substantially all of the acid will react anyway. But use of limestone or dolomite aggregate will increase by at least five-fold the amount of acid required to react with a cubic foot of concrete. It is to be expected that there would be a corresponding slowing of the rate of penetration of concrete.

An attempt was made to test calcareous aggregates in sewer atmospheres. Specimens of five different compositions were prepared, in the form of 2 x 4 in. cylinders. These were placed in duplicate in a manhole in Norfolk, Va., through the cooperation of the Hampton Roads Sanitation District. The manhole was at the end of a force main, with extremely severe hydrogen sulfide conditions. When the specimens were removed in less than a year, corrosion was far advanced (Fig. 1).

In a place where the air is turbulent, various specimens do not have the same exposure. Unless their places are exchanged from time to time, one does not necessarily get a true picture of their relative susceptibilities. Thus, the two specimens of the second mix (limestone rock, silicious sand) show very different amounts of corrosion. But if one considers the average performance for each pair, the results seem to offer quite strong confirmation of the deduction that the life is increased by incorporation of limestone.

Occasionally, in the United States and elsewhere, limestone has been used for concrete pipe because it was the available aggregate. Specifying limestone aggregate for fortifying sewer pipe against acid attack is relatively new. On the basis of a publication by Stutterheim and Van Aardt (1) and the results of the tests shown in Figure 1, the City of Tuscaloosa, Ala., specified limestone aggregate for trunk sewers where there was a likelihood of a small amount of sulfide, or where a factor of safety was desired. Several miles of trunk sewers in sizes up to 48 in., were installed there in 1958, using concrete pipe having limestone aggregate. The City of Palm Springs, California, is presently requiring limestone aggregate for some of its sewers.

Additional Concrete

A good protective material for concrete is concrete. The rate of penetration of ordinary concrete is slow under moderate sulfide conditions. In 1946, Pomeroy and Bowlus (6) made an estimate that under average flow conditions (velocities of 2 to 3 fps) an average dissolved sulfide concentration of 0.1 ppm would lead to attack of the interior of a concrete sewer at a rate of about 1 in. in a century. This estimate still appears valid. This would generally mean average daytime concentrations and average summer concentrations considerably higher, with summer total sulfide concentrations reaching peaks of 2 to 3 ppm. There are a good many sewers where concentrations as high as this may be found. Rate of penetration is proportional to the dissolved sulfide concentration, other things being equal. The value of extra concrete where moderate sulfide conditions prevail is evident. Many cities have required 1 in. or 1½ in. of extra concrete in pipes where sulfide conditions are likely.

Even in the presence of severe sulfide conditions, with maxima of 10 to 15 ppm total sulfide, concrete pipe can be given long life if it has both extra thickness and limestone aggregate. Rarely should this be necessary for sewer pipe. For junction chambers and other structures where there is much turbulence, with abnormal release to the air of hydrogen sulfide, and for manholes at the ends of long force mains, this combination of protective measures may be desirable.

Summary

1. No kind of hot-applied or solvent-applied coating has been found which holds promise of usefulness for protection of the interior of concrete sewers against the acid formed where high sulfide concentrations are present. A resin polymerized in place has a possibility of being beneficial.

2. Clay liner plates have remained intact only where there is practically no sulfide in the sewage, or where they are submerged daily.

3. A polyvinyl chloride sheet, "Amerplate," is successful. Its life is not known. A guess, based on the limited information available, is that it exceeds 25 years but is less than a century.

4. Attempts to increase resistance of the concrete to acid attack in sewers by impregnating the pores of the concrete with any material are futile.

5. When immersed in acid, concrete specimens prepared in ways which give them high sulfide resistance last longer than do specimens having poor sulfate resistance. Sulfate resistance is imparted by attaining a concrete of low permeability, by use of Type II instead of Type I cement, or by favorable curing procedures.

6. Interpretation of results of laboratory tests in terms of probable life in a sewer must be done with caution, because of the lack of similarity. Under conditions of slow acid production on the inside of a sewer, the rate of reaction of the acid is usually the rate of acid production.

7. Rate of attack, other things being equal, is inversely proportional to the amount of acid-neutralizing materials, including cement, in the concrete.

8. Limestone or dolomite aggregate retarded the attack of concrete specimens immersed in vessels of acid, of specimens hung in a manhole with very high sulfide concentration, and of pipe laid in a line carrying septic tank effluent. Use of either of these alkaline aggregates is expected to increase the life of a concrete sewer, in a place where sulfide conditions prevail, by at least five fold.

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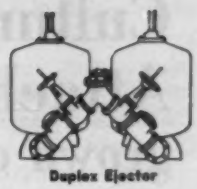

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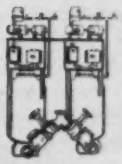

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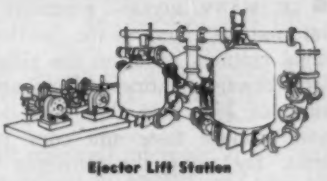

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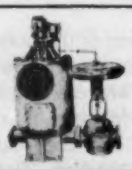

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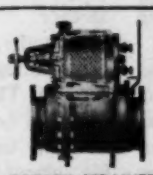

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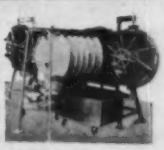

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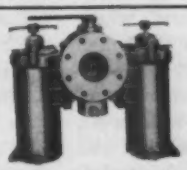

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Culture and Harvest of Attached Algae
grown on domestic sewage

Part 1

by GEORGE W. REID, Prof. of Sanitary Engr. and JOSEPH R. ASSENZO, Asst. Prof. of Sanitary Engr., University of Oklahoma, Norman, Oklahoma

EDITOR'S NOTE: This Research Progress Report is presented in two parts. Discussed here are some considerations involved in the use of attached algae to improve wastewater plant effluents and their possibilities as a food source. Part 2 describes laboratory studies and pilot plant operations. This work has been performed under U. S. Public Health Service Research Grant RG-5422.

■ IN MANY RIVERS, especially the intermittent rivers of the Southwest, algal cultures grow on the effluents from sewage treatment plants, and in time of low flow they die, decay, and produce taste and odor problems. By using the nutrients contained in the sewage to grow a controlled algae culture, this stream pollution problem may be eliminated. Conventional sewage treatment does not utilize the nitrogen and phosphorus of the sewage; this is a waste of useful elements which is unnecessary. These are nutrients which the algae can utilize and, in turn, the harvested algae may be used for feed and/or fertilizer.

It has been estimated that domestic sewage could produce from 1,200 to 1,400 pounds of protein per day from a population of 10,000 persons. Algae grows well in domestic sewage which has adequate nutrients and which flows on a sustained basis. Although domestic sewage does carry some industrial wastes, the wastes are not usually sufficiently toxic to prevent algal growths. Consequently, if the studies with algae prove successful, the results will be improved effluents and a new food source.

In the near future, expanding growths of cities will cause the increased discharges of sewage effluents in the proximity of surface water intakes. As such, particularly in the Southwest where the only stream flow in dry weather may be treated sewage, bacterial, nitrogen and phosphorus removals greater than are ordinarily encountered in conventional sewage treatment will be mandatory. There is evidence that algae under controlled conditions will accomplish this.

In the business of water resource development as greater BOD removals are experienced, nutrified effluents become pollutants. The extent of current knowledge dictates dilution, with 90 per cent or greater BOD removal, of 3 to 4 volumes of stream flow per volume of sewage effluent to prevent algae trouble. This implies the need for 4 volumes of stream flow to develop 1 volume of usable municipal water. Low flow augmentation and not water demands may become the limiting growth factor in the Southwest.

The advantages of using algae as a source of oxygen in conjunction with the aerobic bacterial decomposition of sewage has been pointed out by many investigators. Since oxygen is only slightly soluble in water, using atmospheric oxygen is a very slow and expensive process. The carbon dioxide, ammonia, phosphates and many trace elements released by the bacteria are necessary for the growth of algae. There is established a type of symbiosis when algae and bacteria are cultured together in sewage.

The organic matter produced by the algae themselves is greater than the organic matter in the sewage. Therefore, it is necessary to harvest the algae at regular intervals. Because algae grown in sewage have a high protein content and can be used as a source of food, the economics of the process has some attraction which have stimulated researchers beyond the health aspects of the situation. Through a long series of investigations, Gotaas[1, 2, 3, 4, 5, 6, 7, 8, 9] and his co-workers have quantified the process involved and worked out many of the engineering problems encountered in such a program. Their work has been done primarily with unicellular, or free-floating, forms of algae. One of the major difficulties has been finding a practical and economical method of harvesting the unicellular forms of algae. Because of the gelatinous nature of the cell walls of these organisms, ordinary filtering processes are far too slow and ineffective. Although several methods have been tried [5, 9], none up to now have proven entirely satisfactory.

Actually, harvesting is the only real disadvantage of the free-floating process. The algae are easily grown, they can be grown in large numbers in tanks or basins, and they can be fed chemicals and carbon dioxide. Processwise, aside from harvesting, a sewage treatment process prototype such as activated sludge would certainly be feasible, wherein organic material is oxidized by free-floating slime, settled and the slime returned.

One obvious approach to harvesting would be to use attached forms. If algae can be grown naturally on surfaces, scanning and scraping are quite easily accomplished. Sewage is also treated by slimes grown on surfaces in such devices as the contact-aerator and the trickling filter. Why could not this serve as a prototype for a plant to grow and harvest attached algae? It was envisioned that the principal practical problem would be concerned with the ability to provide enough usable surface area, all exposed to sunlight. In sewage treatment sunlight is not necessary; so to be feasible attached algae must take up the nutrients, not just as rapidly, but more rapidly than bacterial slimes. To point up, for comparative purposes, it must be ascertained whether the ease of harvesting attached algae will offset space requirements for growth.

Many other questions present themselves; for example, the adaptability of algae to temperature and sunlight changes, effects of toxic material, actual amount of nitrogen and phosphorus remaining in the effluents, types of algae and bacteria, and the interrelationship of bacterial and algal growths. All of these data, of course, must be for attached cultures.

Search For Suitable Algae

Studies were conducted at the University of Oklahoma to investigate the feasibility of developing an attached algae on sewage effluent. It was hoped the algae would reduce the nutrient content of the sewage sufficiently to prevent stream pollution, especially in dry weather flow receiving streams. The study was divided into three phases: A, investigations to determine suitability of attached algae for cultivation in sewage; B, trial cultivation and harvesting of algae on bench-scale, or laboratory scale, apparatus; and C, development of pilot-scale algae cultivation apparatus.

The first phases of the current study were concerned, of course, with the reported work of others and with field investigations for algae suitable for laboratory culture.

If one considers the entire number of species of algae, the range of conditions under which they will grow is quite wide. The largest number of algae grow in a water habitat. Some of these are found in flowing streams, some in lakes and ponds, some in pools and ditches, and other in bogs and swamps. Those found in flowing streams vary according to the speed of the water. For example, those on a waterfall are quite different from those found in the slower flowing parts of a stream. Those found in lakes and ponds may be subdivided into two groups: A, the attached forms, and B, the free-floating or plankton forms. The species found in bogs and swamps vary from those that form gelatinous masses on submerged plants and other objects to those that grow at the interface between the water and the atmosphere.

The temperature range under which algae will grow, depending on the species, is extremely great. Certain species reach the optimum growth rate only in conditions of full sunlight, while others will grow only under shady conditions. While there is a geometric decrease in intensity of illumination with an arithmetic increase in the depth of water, many species show a greater rate of photosynthesis at a certain depth than they do at the surface. There is, of course, a qualitative penetration of light in water. The greatest amount of absorption is at the red end of the spectrum, while the violet end penetrates the greatest distance. This results in a vertical distribution of attached species in deep bodies of water.

The elements essential for the growth of algae are the same as for higher plants with minor variations. Calcium is not essential for some species of algae. Some elements are toxic to the algae. Iron is the most common one in nature. If the iron (Fe_2O_3) content of water gets above 5 mg per liter, there is a distinct toxic effect. Although algae are frequently found in waters containing more iron than this, the toxic effect has been neutralized by the buffer effect of organic compounds of calcium salts. Most algae grow well when the source of nitrogen is either nitrites, nitrates or ammonium compounds.

Geigel[10] found *Chlorella* can withstand up to 30 ppm of Boron before growth was decreased. He also found they could survive in solutions containing up to 140 ppm.

For any particular species, the limitations are fairly narrow. Although the conditions may change greatly, there always seems to be some species of algae which survive the environment of a sewage disposal plant. If the conditions under which the algae are growing are not changed abruptly, the flora will change to the new environment.

With such a great genetic variation as far as toleration for the environment is concerned, it is not surprising to find that many species will grow under the conditions that prevail where sewage is discharged.

Information on attached algae and attached algae in sewage was not to be found. More than a hundred references were covered, forty of which were felt to be of sufficient general information to be included in a bibliography. Ample information was available on the nutrient requirements of free-floating species, sewage tolerant species, the limits of light intensity, frequency, use of interruptions, as well as conversion efficiency[4, 11, 12, 13, 14, 15, 16]. There was data on environmental factors associated with sewage such as temperature, pH, and boron tolerance, as well as the nitrogen and phosphorus levels in sewage[1, 2, 3, 10, 17]. Algae culture techniques using free-floating species were also well covered[5, 7, 9, 18, 19, 20, 21, 22].

The only real reference to attached algae grown in sewage was one by Letts in 1913 concerning *Prasiola crispa*[23]. According to Letts, it grew well in a sewage environment using tremendous quantities of nitrogen. A six-month search for this species resulted in finding some in Alaska. These algae were not adaptable to our environmental criteria. Gloyna in his studies did indicate the presence of attached forms in lagoons and that these appeared to thrive at higher organic levels than did the free-floating[24].

The only approach available as a result of this review was to take to the field and locate algae in sewage environments and then bring them to the laboratory for cultivation. Field trips were conducted on the rivers and streams in Oklahoma and particularly in sewage outfalls. Numerous samples were brought to the laboratory. Sewage plants were also studied and yielded samples.

The most profitable source of information on free-floating algae and sewage use was the sewage lagoon or stabilization pond. Oklahoma has

many of these operating under a variety of conditions; some receiving raw sewage, some secondary effluents, and some used as polishers. Ten ponds were selected for study and to obtain sewage tolerant species, and also to learn about nitrogen, phosphorus and bacterial removals.

Two surveys of several stabilization ponds in the Oklahoma area were conducted. One survey was conducted during the latter part of May, 1959, and the second was conducted during the middle of January, 1960. One purpose of the surveys was to determine the density of and species of algae found during both seasons, summer and winter. Another purpose was to determine the efficiency of these stabilization ponds in removing nutrients.

It was found that the most dense algal population was in stabilization ponds whose influents were previously treated. Raw sewage ponds were sparsely populated, relatively speaking. As might be suspected, the greatest removal of nutrients was by ponds with the greater algal densities.

Culture and Harvesting of Attached Algae Grown on Domestic Sewage

Part 2

EDITOR'S NOTE: Part 2 of this presentation on attached algae as a means of improving wastewater plant effluents and algae potential as a food source describes laboratory studies and pilot plant operations and proposes further algae research before engineering studies are continued. The work has been performed under U. S. Public Health Service Research Grant RG-5422.

by GEORGE W. REID, Prof. of Sanitary Eng. and JOSEPH R. ASSENZO, Asst. Prof. of Sanitary Eng. University of Oklahoma Norman, Oklahoma

Laboratory Studies

■ THE LABORATORY studies involved the use of a cascade unit, which in the initial studies proved to be the most effective for growth of attached algae. The unit consisted of a cascade, an inclined plane, and a recirculation tank, in which multiple revolving drums were placed. The volumetric capacity was four gallons.

Treated municipal sewage from the Norman, Oklahoma, Sewage Treatment Plant, a "bio-sorption" plant, was the liquid used in the studies. Two conditions were investigated in these uptake and growth and studies: a, batch operation, and b, continuous operation with recirculation. Analytical determinations included ammonia, nitrate, nitrite, total nitrogen, total phosphate, temperature, pH, light intensity, BOD, solids, and alkalinity.

Batch Operations

The main purpose of the batch operation studies was to determine uptake rates, and for this reason the algae were harvested only after the testing had been completed.

In one series of batch studies, the pH was controlled to determine the pH range at which best growth was obtained. It was found that best growth is obtained between a pH of 6.5 to 9.5; however, the maximum concentration of algae occurred between pH 6.5 and 7.5. At a pH of 9.5, the algae decreased in number and lost much of their color, becoming yellowish-brown.

In a second series no attempt was made to control the pH, but the

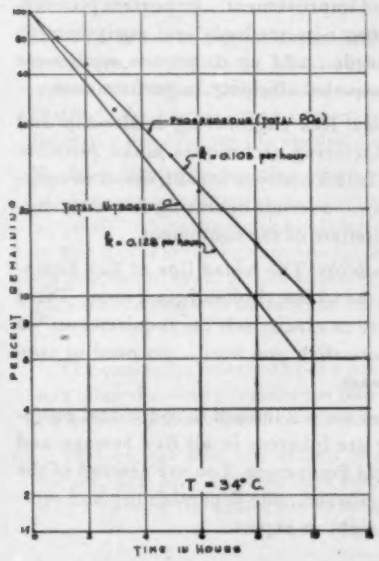

Fig. 1. LABORATORY STUDIES Batch Operation Series 1, using sewage treatment plant effluent.

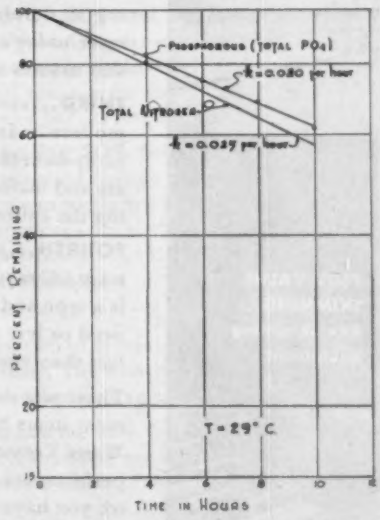

Fig. 2. LABORATORY STUDIES Batch Operation Series 2, using sewage treatment plant effluent after 24 hours aeration.

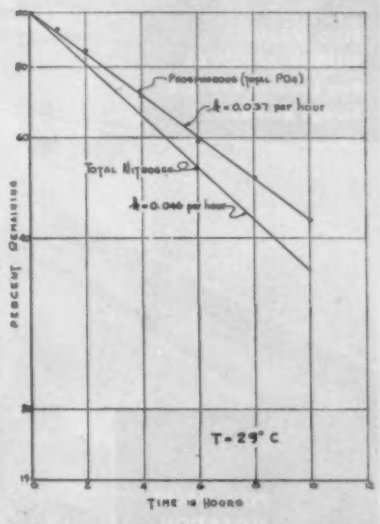

FIG. 3. LABORATORY STUDIES Batch Operation Series 3, using sewage treatment plant effluent with NH_4NO_3 added.

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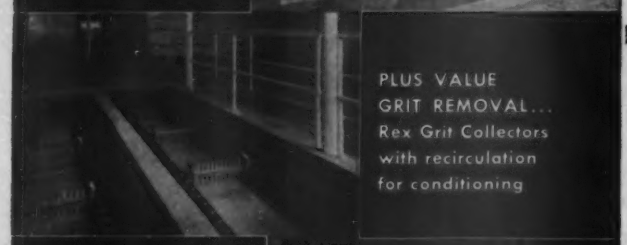

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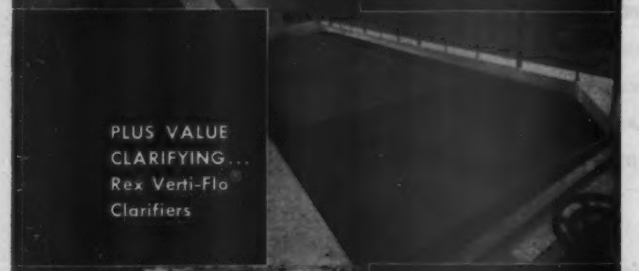

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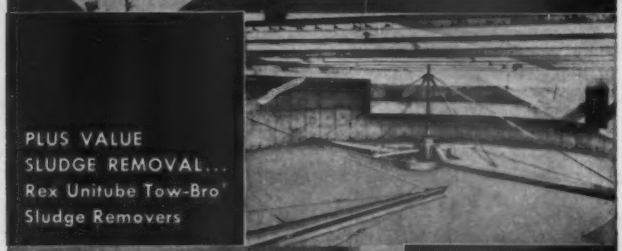

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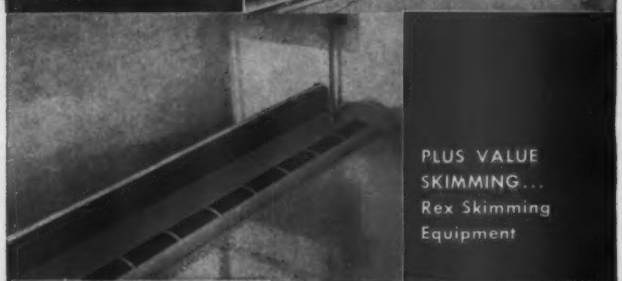

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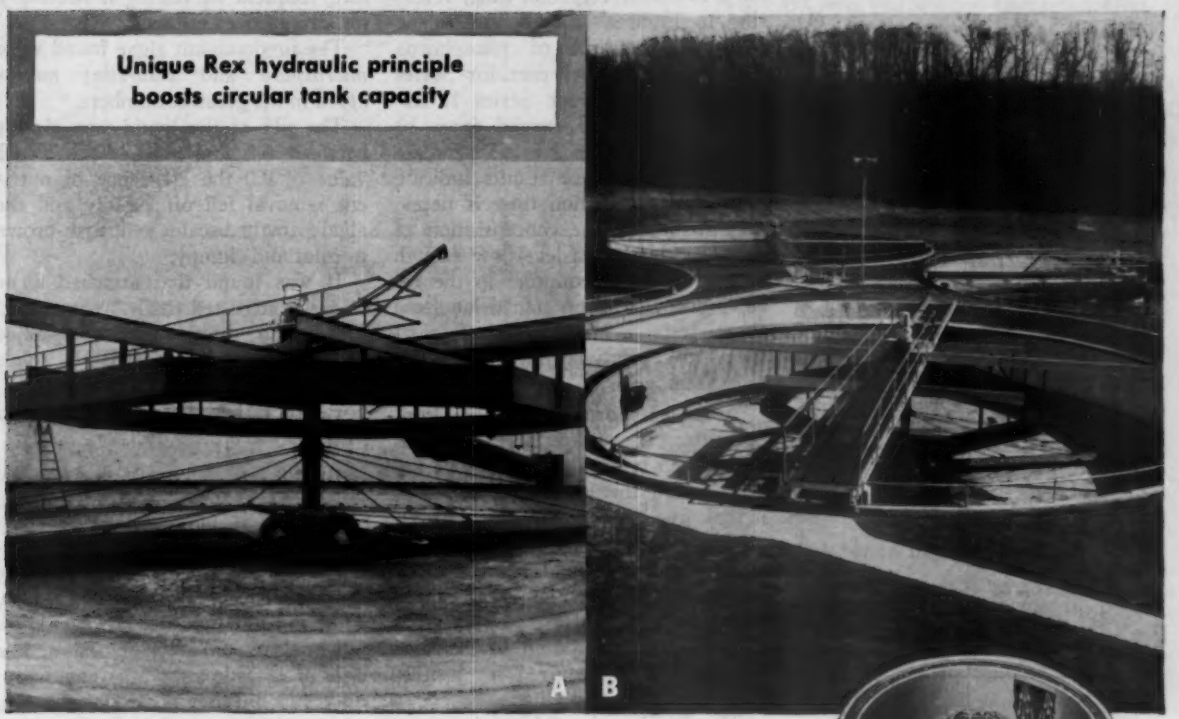

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sewage was treated chemically or physically before being added to the unit on which the algae had been previously cultivated. Figures 1, 2, 3, and 4 show graphically the results of four series of tests. For each series the reaction velocity constant, or k value, was computed for both phosphorous and nitrogen uptake from the equation:

$$\log \frac{L_t}{L} = -kt \qquad (1)$$

where:

t = time in hours
L = initial concentration
L_t = concentration at time, t
k = reaction velocity constant per hour, (base 10)

Table 1 gives a comparison of the k values for the four series for a temperature of 20° C. These k values are quite low when compared to the k value obtained by Reid[25] in his slime studies. Reid obtained a value of 0.1 per hour for phosphorus uptake by slimes; the values obtained in this study vary from 13 to 60 per cent of Reid's value. It is believed that algae, cell for cell, take up nutrients at the same rate as slime, but that the difference in cell size accounts for the difference in k values, the cell size of algae being considerably larger than that of slime bacteria.

The k values also reflect the efficiency of the process. For example, for a two-hour retention time, referring to Figures 1, 2, 3, and 4 the per cent removal of phosphorus ranged from 10 per cent for Series 2 to 40 per cent for Series 1. Removal of nitrogen ranged from 10 per cent for Series 2 to 45 per cent for Series 1. These results indicate that a high retention time is necessary to reduce the concentration of these nutrients to a level low enough to prevent algal pollution in the receiving stream. One conclusion from these tests is that attached algal forms are "relatively inefficient" nutrient removers.

Another important economical consideration is surface area required for a given removal in a given period of time. In the results of Series 1, it took five hours to remove approximately two-thirds of the phosphorus. Assuming a one mgd sewage treatment plant and a ⅛ in. sheet of liquid over an algal growth, six acres of surface area exposed to the sunlight would be required for a five-hour retention period.

The BOD and solids analyses indicated, as was already known, that algae produce more organic matter than is in the original liquid. Therefore, frequent harvesting is necessary for an improved effluent.

The predominant algae found were *microspora* and *chlorella*; *microspora* in the greatest numbers.

The pH of the liquid was always between 6.5 and 9.5. Above a pH value of 9.0 the efficiency of nutrient removal fell off rapidly and the algal growths became yellowish-brown in color and clumpy.

It was found that attached algae may be harvested easily by scraping. Harvesting should be accomplished at some critical value of BOD, solids and pH; pH being the most important, rather than being just a visual and arbitrary decision.

Table 1
A Comparison of The k Values For A Temperature of 20°C

Series	k, Phosphorus		k, Nitrogen	
	per hour	per day	per hour	per day
1	0.053	1.27	0.067	1.61
2	0.013	0.31	0.017	0.41
3	0.024	0.58	0.030	0.72
4	0.061	1.46	0.072	1.73

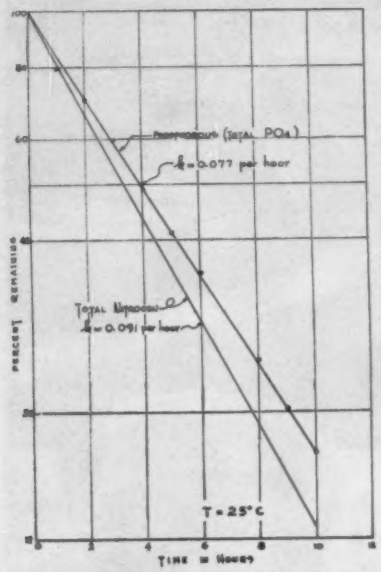

FIG. 4. LABORATORY OPERATIONS Batch Operation Series 4, using sewage treatment plant effluent chemically treated to precipitate phosphate and NH_4NO_3 added.

Continuous Operation

The batch operations were performed mainly to measure the retention time required for the uptake or assimilation by attached algae. They did not indicate, however, how much algae, on a weight basis, this type of cascade apparatus could produce, nor did they provide much data which might be used to predict either pilot plant or full scale continuous operation. To accomplish these objectives, the next studies involved

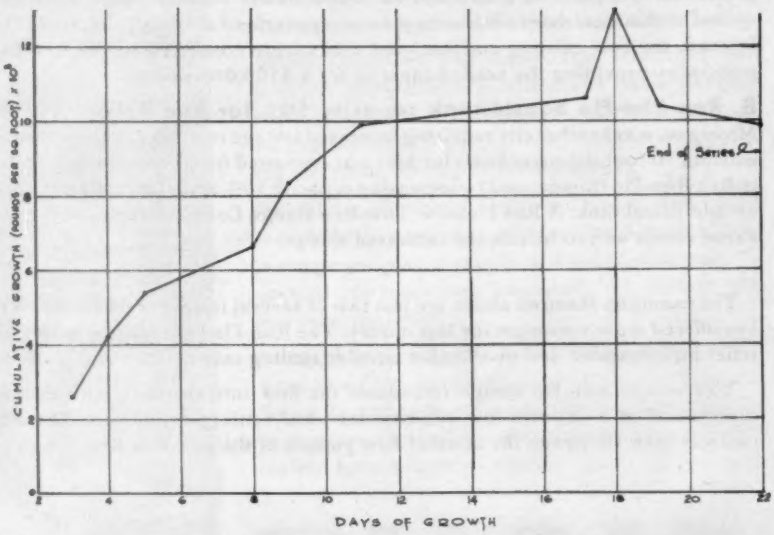

Fig. 5. LABORATORY STUDIES continuous operation Algal Growth, Series 1. Weights are dry weights.

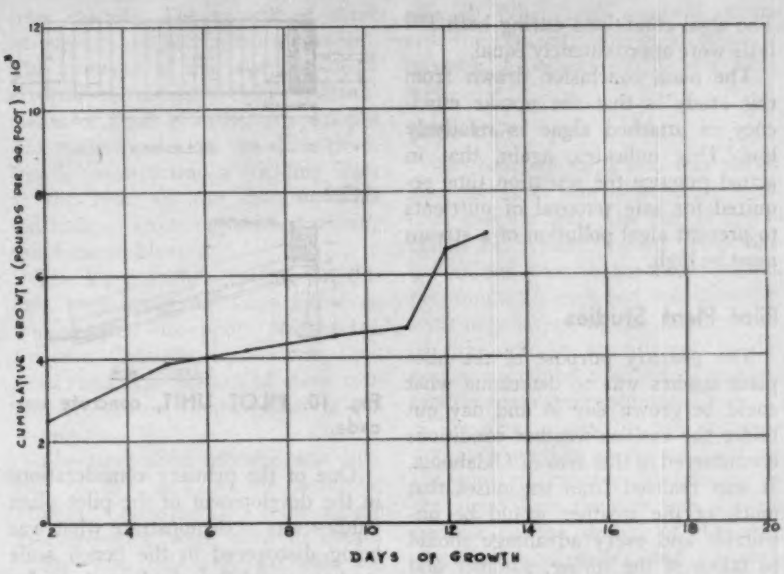

Fig. 6. LABORATORY STUDIES continuous operation Algal Growth, Series 2. Weights are dry weights.

continuous operation of the cascade unit. A larger recirculation tank was added to increase the retention time.

The same chemical and physical tests were performed. In addition, alternate steps on the cascade were harvested daily in order that accumulative weights might be determined. At various times, when the pH became too high, the entire unit was drained, cleaned and flushed, and a new growth started by seeding. *Microspora* and *chlorella* were the predominating species. Figures 5, 6, and 7 show the results of the cumulative growth studies for three series of tests. The characteristic humps on Figures 5, 6, and 7 reflect change in light intensity and indicate the unit was operating far below optimum light intensity. The source of light was a battery of flood lights. After maximum growth is obtained on the cascade, the attached algae slough because the layer of algae adjacent to the cascade surface receive little or no light, turn brownish-yellow in color and die. The phosphorus and nitrogen removals tapered off after 14 to 18 days growth without harvesting. After this time, the uptake of nutrients was beginning to be offset by that released by the dying algae.

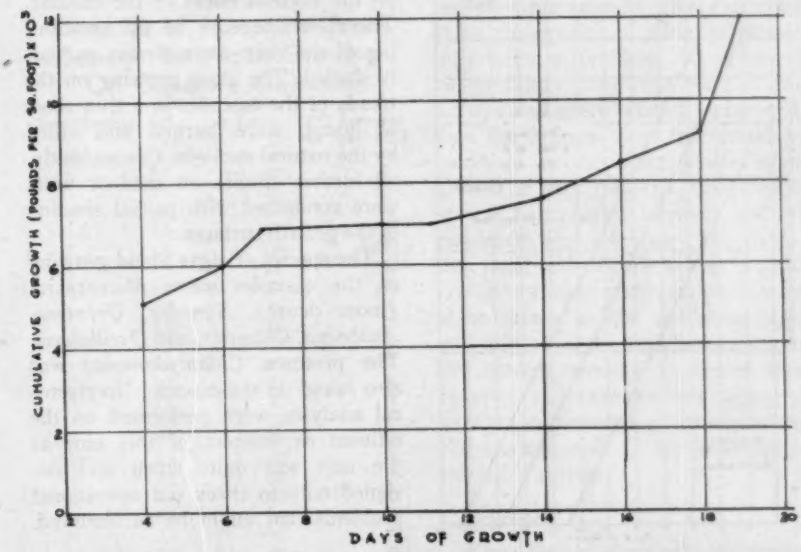

Fig. 7. LABORATORY STUDIES continuous operation Algal Growth, Series 3. Weights are dry weights.

Retention time and surface area were again limitations as they were with the batch operations. The problem of area required for the attached algal forms seems to be an insurmountable one. Based on the figures obtained in these studies, after a two-week growth time one ton of algae would be obtained from three acres of cascade provided the effluent was recirculated through an oxidation pond. Because the light intensity generally observed in this area of Oklahoma is much higher than was used in these studies, this same weight could be obtained in about one week rather than two weeks, if partial shading is used to obtain optimum light.

As was expected, the efficiency of removal of the nutrients was somewhat lower than that obtained in the batch operations. Efficiency in this case is a function of residence time.

The calculations clearly indicated that with the recirculation requirements, etc., the attached forms, at this stage, do not lend themselves to plant scale design because of the tremendous areas required. Mixing with free floating forms found in algal ponds might help some, but it would still be necessary to harvest these free floating forms in order to have an improved effluent.

P^{32} Uptake Studies

A series of tests to evaluate reaction velocity constants were performed using radioactive phosphorus (P^{32}). In these tests, the cascade unit was operated on a batch basis. The radiophosphorus was introduced into a synthetic sewage and this was fed into the algae seeded unit. The radioactivity was detected with a Geiger-Mueller (GM) tube which was placed two inches above the algal growth on one of the steps of the cascade.

Two series of tests were conducted. Figures 8 and 9 show the results of these tests. The k values were calculated in the same manner as previously described. The k value obtained from the results of Test 1, for 20° C, was 0.0215 per hour; for Test 2 the k value was 0.0224 per hour. Also plotted on Figure 9 is Reid's k value for the uptake of P^{32} by slime[25]. As can be seen from the figure, the k values for uptake of radiophosphorus by the attached algae are about one-tenth of the k value for the uptake of radiophos-

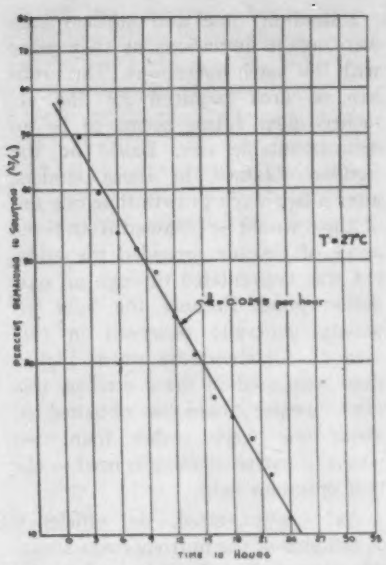

Fig. 8. UPTAKE OF P^{32} by attached algae, test no. 1, run no. 3 only.

phorus by slimes. This discrepancy is due primarily to the difference in total surface area or numbers per unit area of the slime and attached algae. The slime, of course, offers much greater surface area because of the smaller size cells. Also, the algae immediately next to the surface of the cascade receive but little of the necessary light in comparison to the algae nearest to the light source, thereby reducing their assimilation efficiency.

The k values obtained in the uptake of radiophosphorus compared favorably with the k values determined by chemical analysis. Table 2 presents the k values for phosphorus uptake by both methods.

Table 2

k Values For Phosphorus Uptake By Both Methods

	k Values, Per Hour, T = 20°C	
Test Number	Chemical Analyses	Radiophosphorus
1	0.053	0.022
2	0.013	0.022
3	0.024	
4	0.061	

At first glance at the results, they would seem to indicate that the k values determined by measurement of the radioactivity gave more consistent results than the chemical analysis method. Differences in the k values determined by chemical analysis reflect varying algal conditions during testing: age, pH, temperature, organic content, light intensity, etc. The algal conditions during both P^{32} tests were approximately equal.

The main conclusion drawn from this study is that the uptake efficiency of attached algae is relatively low. This indicates, again, that in actual practice the retention time required for safe removal of nutrients to prevent algal pollution of a stream must be high.

Pilot Plant Studies

The primary purpose of the pilot plant studies was to determine what could be grown day in and day out under the various weather conditions encountered in this area of Oklahoma. It was realized from the onset that much of the weather would be unsuitable and every advantage should be taken of the spring, summer and fall weather. Consequently, the pilot plants were placed in operation before the laboratory studies were completed.

Four plants were constructed, all of them based on the cascade principle. One was a cascade built of wood, the second, of concrete, the third, corrugated metal, and the fourth, a cascade with baffles made of concrete to increase the retention time. The units were constructed at the Norman, Oklahoma, Sewage Treatment Plant and were designed to receive sewage from the secondary settling basins. No recirculation was practiced.

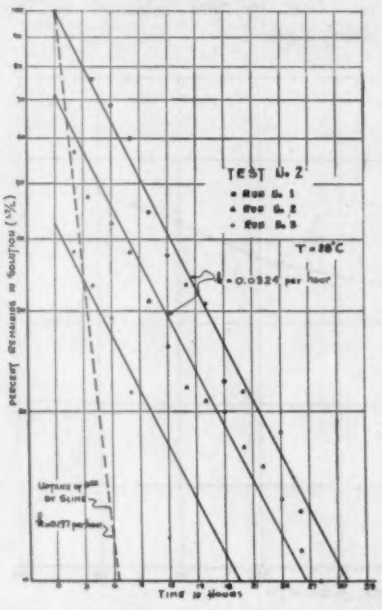

Fig. 9. UPTAKE OF P^{32} by attached algae.

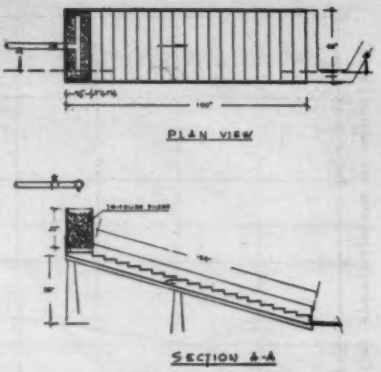

Fig. 10. PILOT UNIT, concrete cascade.

One of the primary considerations in the development of the pilot plant studies was to demonstrate what was being discovered in the bench scale studies could be duplicated under natural conditions. The units were placed into operation with varying degrees of success, and as more was learned they underwent continuous modification. The most pressing problems encountered were the attendant growth of sewage slime with the algae and the vicissitude of the weather, which ranged from overly intense sunlight to killing frosts.

Wooden Cascade

A wooden cascade was the first unit constructed. The results of the initial studies showed algae could be grown on the wooden cascade, but a problem would be encountered with the growth of slime during the night. The most dense growth of algae was on the vertical risers of the cascade. The risers, because of the positioning of the unit, were always partially shaded. The algae growing on the treads of the cascade, in a thin sheet of liquid, were burned and killed by the natural sunlight. Consequently, all further studies on outdoor units were conducted with partial shading of the growth surfaces.

The species of algae found growing on the cascades were: *Microspora*, (most dense), *Synedra*, *Urenema*, *Anabaena*, *Chlorella*, and *Oscillatoria*. The protozoa *Chlamydomonas* was also found on the cascade. No chemical analyses were performed on the effluent or influent of this unit as the unit was quite small and designed only to check out operational problems that might be encountered.

Concrete Cascade

Figure 10 is a plan of the con-

crete cascade. The growth of slime on the cascade was again a problem. The presence of the slime made it difficult to obtain weight measurements of algal growths. An attempt was made to alleviate the slime problem by constructing a trickling filter at the head of the cascade. This did little, if anything, toward solving the slime problem.

The algae found growing on this unit were about the same found on the wooden cascade: *Microspora, Synedra, Chlorella, Oscillatoria, Urenema,* and *Anabaena.* The slime contained protozoa, fungus, bacteria and worms.

The algae-slime mixture was difficult to dry and became anaerobic rapidly. Consequently, good weight measurements were hard to obtain.

The flow rate over the unit was one gallon per minute initially and then increased to three gallons per minute. The higher flow rate washed most of the slime from the cascade without dislodging much of the attached algae. The average retention time was 20 to 30 seconds. Physical and chemical analyses were conducted at least daily. As might be expected there was little or no removal of the nutrients with such a small contact period. Table 3 shows the results of 22 analyses for phosphate. As can be seen in the table, about 70 per cent of the analyses indicated no measurable removal. However, when there was removal, it was rather high for the short contact time existing. When high removal occurred, the concentration of algae-slime mixture, especially slime, was very high.

Table 3
Removal of Phosphate From Sewage By Algae Growing On Concrete Cascade

Test Number	pH	Temp. °C	%Removal of Total PO4
1	7.9	30	0
2	8.4	32	23
3	8.0	28	0
4	7.9	29	0
5	8.0	26	47
6	7.9	28	35
7	8.1	29	0
8	7.9	28	14
9	8.0	30	0
10	7.9	31	0
11	8.1	31	0
12	8.3	31	0
13	7.9	32	0
14	8.0	29	0
15	7.9	29	0
16	8.4	30	7
17	8.3	30	7
18	8.3	30	0
19	8.1	30	0
20	7.9	30	0
21	7.9	30	0
22	7.8	29	0

Baffle Unit

The concrete baffle unit was placed into operation shortly after the concrete cascade unit. The rate of application of sewage varied from one gallon per minute to three gallons per minute. A rock bed was installed, with no success, at the influent end of this unit in an attempt to decrease the slime problem. The contact time was three minutes.

The algal growth in this unit was not as abundant as it had been on the concrete cascade. Harvesting of the algae-slime mixture was difficult because of the design of the unit. *Oscellatoria, Synedra,* and *Chlorella* were the main species of algae found growing on the unit. Results of the physical and chemical analyses were similar to the results obtained with the concrete cascade. Table 4 shows the results of the unit for phosphate removals. As can be seen in the table, half of the time there was no measurable removal of the phosphate. Of the instances when removal occurred the maximum removal was only 10 per cent. This was due primarily to the lack of contact time and reflects the greater growth of slime on the concrete cascade unit.

The pilot studies indicate: a, a once-through system is completely inadequate unless much area is made available to increase the retention time; b, in the operation of a pilot or full scale unit to grow attached algae the growth of slime is certain to present a problem. However, if an oxidation pond was part of the set-up and recirculation practiced, then the influent flow rate could be increased to the point where slime growth is kept minimal, the influent sewage more highly nitrified, and the residence time adequate; the oxidation pond and cascade set-up is preferable to simple recirculation because algae grown in the oxidation pond will adhere to the attached forms on the cascade causing a greater total removal of nutrients and algae; c, as far as harvesting is concerned, the cascade unit is far superior to the baffle system.

Table 4
Removal Of Phosphate From Sewage By Algae Growing On Baffle Plate

Test Number	%Removal of Total PO4	Temp. °C	pH
1	3	34	7.7
2	4	35	7.9
3	0	36	8.0
4	10	37	8.0
5	12	36	7.7
6	0	30	7.8
7	9	31	7.7
8	0	29	7.7
9	0	30	7.9
10	6	29	7.7
11	0	30	7.7
12	0	30	8.0
13	5	31	7.7
14	0	24	7.8
15	10	25	7.8

Conclusions

Experiments designed to explore the feasibility of developing an attached algae on sewage effluent to reduce the nutrient content of the sewage have been successfully conducted, and it can be concluded that attached forms can be grown on shallow water depth surfaces or on moving surfaces, and that these algae can substantially remove the nitrogen and phosphorus from the sewage.

An extensive literature research was first conducted for references to attached algae suitable for growth in sewage. Little was available. Secondly a field search, at sewage outfalls, in polluted streams, and at sewage lagoons, for attached algae suitable for culture was undertaken. Several promising species were collected and grown on bench-scale apparatus.

Both bench-scale and pilot-scale apparatus providing shallow water depth surfaces were constructed and were operated sufficiently long to arrive at the above conclusions. Numerous operational and laboratory difficulties were encountered but surmounted, including, particularly, species interaction and nutrition.

Though it has been demonstrated that attached algae can be grown, removed by scanning and will remove the phosphorus and nitrogen in the food sources, namely sewage, the residence time required for effective reasonable removals is not compatible with what one would desire for plant scale operation. Studies indicate it takes 5 hours to remove ⅔ of the phosphate with possibly ¼ growth exposed to subdued sunlight. Roughly calculating for 1 mgd capacity plant, it would require 6 acres of algae surface for 5 hours

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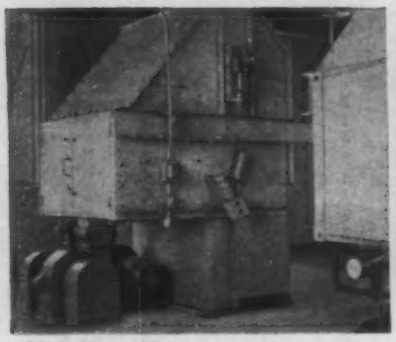

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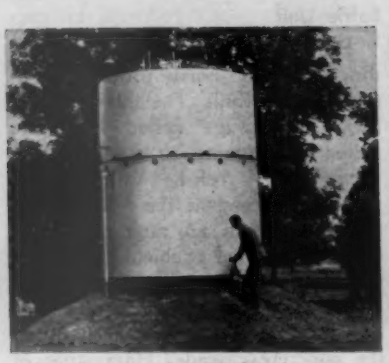

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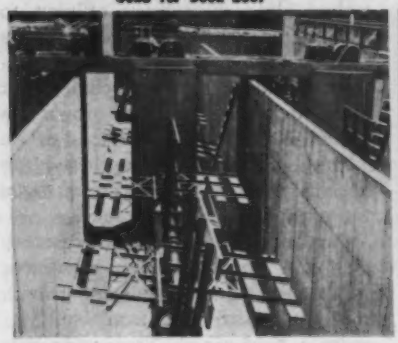

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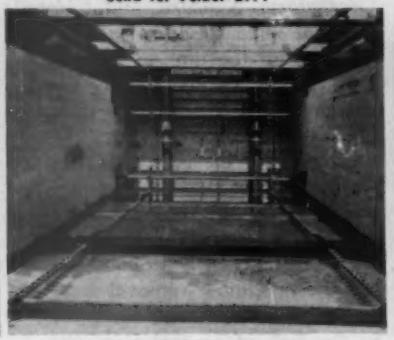

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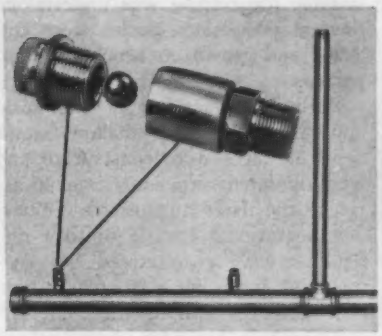

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retention, compared to a high rate trickling filter, requiring 1/30 of an acre of about 180 times more effective in use of area. The difficulty, of course, is that the algae surfaces require not only intimate contact with the sewage but also light. Slime surfaces can be built as multiple decks without respect to light. Area for area, it appears that attached algae are as active in nutrient utilization as free-floating forms, but the free-floating forms can present more algae per unit surface. It was envisioned that algae uptake of nutrients might be much more rapid, thus lowering retention time requirements than have been determined so far.

As a consequent of this study, it is believed further studies by algologists are needed before engineering-type studies can be continued on attached forms utilized to treat sewage effluent.

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Algae Growth Rate

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■ THE ECOLOGICAL RELATIONSHIPS of any biological waste treatment process are undoubtedly complex. Since a stabilization pond depends upon the presence of autotrophic organisms as well as heterotrophs for proper operation, it is biologically more sophisticated than the other conventional treatment processes.

It has been postulated [1] that in a stabilization pond the heterotrophic organisms, bacteria, fungi, and protozoa, oxidize waste organic matter excreting carbon dioxide, ammonia, and other inorganic compounds which may serve as nutrients for the algae present. In turn, the algae produce oxygen for the heterotrophs as a by-product of photosynthesis. This hypothesis, although valuable as a starting point for discussions of the ecology of stabilization ponds, is a simplification of the actual situation.

It has been known for some time [2] that many of the algae, notably Chlorella and Scenedesmus, which often occur in stabilization ponds, are able to utilize a variety of organic compounds as carbon sources, nitrogen sources, or energy sources. More recently it has been reported that under certain cultural conditions *Chlorella pyrenoidosa* will reduce the concentration of organic material in sewage when grown in the absence of bacteria [3]. Thus some of the algae in a stabilization pond are able to utilize some of the waste organic matter directly. Whether or not this actually occurs and what effect it would have on the growth of the algae has not been established previously.

This investigation was a study of the effect of some organic materials, both pure organic compounds and organic matter extracted from sewage, on the growth rate of an alga which commonly occurs in stabilization ponds. It was designed to provide information which might indicate if stabilization pond algae do actually assimilate organic matter from waste waters, the growth conditions under which this assimilation might take place, and what effect it would have on algal growth.

Methods

The test organism used in this series of experiments, is a strain of *Chlorella pyrenoidosa* which was isolated from a stabilization pond. It is the same strain which was used in previous experiments to determine if organic matter from sewage could be assimilated by algae [3].

The technique of testing was to determine the growth rate of *Chlorella pyrenoidosa* grown on an inorganic medium and, at the same time, the growth rate of the alga in cultures to which the test material has been added. The growth rate was measured by determining the packed cell volume at two different times during the period of active growth and calculating the growth constant, k_g, from the formula:

$$K_g = 1/t \log V_o/V_t,$$

where t is the time of growth, V_o is the initial packed cell volume, and V_t is the packed cell volume at time t [4].

The inorganic medium used in this investigation was a modified Knop's solution containing 722 mg KNO_3, 44 mg KH_2PO_4, 75 mg $MgSO_4$, 3.6 mg $Fe_2(SO_4)_3$, 1.4 mg $CaCl_2$, 5.4 mg H_3BO_3, 1.24 mg $ZnSO_4$, 1.36 mg $MnSO_4$, .75 mg MoO_3, 1.26 mg $CuSO_4$, and 1.1 mg $CoCl_2$ per liter. It contains all of the nutritional requirements for *Chlorella pyrenoidosa* in concentrations which would allow the alga to attain its maximum growth rate when the physical conditions are optimum [5]. Carbon dioxide was provided by aerating the cultures with either compressed air or air enriched with 1 per cent CO_2. It was assumed that carbon dioxide was limiting in the cultures aerated with air, but that the carbon dioxide concentration was not limiting algal growth when the cultures were aerated with 1 per cent CO_2 in air.

The cultures were illuminated by forty-watt, soft white, fluorescent lights. The light intensity at the surface of the cultures was between 175 and 200 foot candles. During the tests the cultures were maintained at a temperature of 25°C ± 2°.

Several groups of pure organic compounds were tested to determine their effect on the growth rate of *Chlorella pyrenoidosa*. The compounds were selected to provide representatives of several types of compounds which are metabolized by many groups of microorganisms. Preliminary tests were carried out in open cultures in which no attempt to exclude bacteria was made. Those compounds which seem to have an effect on the growth rate of the alga were then tested in sterile cultures aerated with air and in sterile cultures aerated with 1 per cent CO_2 in air.

The sewage which provided organic material for some of the tests was collected from a sewage treatment plant which treats primarily domestic sewage. The samples were collected on weekday mornings during a dry period. Eight samples were collected over a two week period to provide a composite sample. A portion of each sample was autoclaved and stored. The remainder of each sample was run through an extraction process which provided six concentrated fractions of the organic material present. The extraction procedure is diagrammed as a flow sheet in Figure 1.

In the process of extracting the ether solution, amorphous precipitate was formed. Apparently, this precipitate was either soap, detergent, or the product of the saponification of some fats which were extracted from the sewage. It was retained with the aqueous layer throughout the rest of the extraction procedure but showed no tendency to re-dissolve in either the aqueous solution or in the ether. It was finally separated by filtration and labelled fraction *S*.

Results

The results of the preliminary tests indicated a variety of compounds which might increase the growth rate of *Chlorella pyrenoidosa* under some conditions. All of these compounds were tested in pure cultures. The compounds which did not alter the growth rate of the alga in open cultures with inadequate CO_2 were assumed to be inactive as far as the nutrition of *Chlorella* was concerned. Among the compounds tested and found to be inactive were aliphatic alcohols and amines and aromatic carboxylic acids. Of the fatty acids tested, those with six or more carbon atoms had no effect on the growth rate of *Chlorella*.

The results of the tests of organic compounds in pure cultures which were aerated with air are presented in Table 1. Most of these compounds showed some indication of having an effect on the growth rate. The greatest acceleration of growth was given by nitrogen containing compounds such as amino acids, urea, and yeast extract. Since the algae in this culture did not have adequate carbon dioxide, it is probable that these compounds served as sources of both carbon and nitrogen. However, several of the other compounds which accelerated the growth rate could only serve as carbon sources.

The compounds which were found to accelerate the growth rate of *Chlorella pyrenoidosa* in pure cultures where the concentration of carbon dioxide was inadequate were tested in pure cultures having adequate carbon dioxide. The results of these tests are presented in Table 2. Many of the compounds which could serve as nitrogen sources or as sources of both carbon and nitrogen accelerated the growth rate, although the percentage increase was not as great as in the cultures in which the carbon dioxide concentration was inadequate.

The results of the experiments in which the effect of the various fractions of the organic matter extracted from sewage on the growth rate of *Chlorella pyrenoidosa* was determined are presented in Tables 3 and 4. For these tests the organic material from sewage was diluted with the inorganic medium until the concentration in the test cultures was approximately equal to the concentration in the sewage. The experiments whose results are reported in Table 3 were carried out in cultures which were aerated with air, and thus any acceleration of growth may be interpreted in terms of the assimilation of organic carbon. From these data it is apparent that the compounds present in sewage which may serve as carbon sources for *Chlorella* are those which are more soluble in water than in ether and those which form salts in a basic solution. The same compounds could be responsible for the activity of fraction *B* and fraction *C* since the difference in solubility in hydroxide and in bicarbonate solution of many organic compounds is not clear cut.

Table I

Tests of Organic Compounds in Sterile Cultures with Inadequate Carbon Dioxide Supply

Compound	Concentration			
	0	10^{-5}M.	10^{-4}M.	10^{-3}M.
	Growth Rate			
Glucose	0.352	1.094	0.912	0.589
Acids				
Formic	0.348	0.332	0.508	0.418
Acetic	0.364	0.328	0.492	0.392
Oxalic	0.354	0.856	0.644	0.490
Malonic	0.370	0.872	0.718	0.444
Tartaric	0.366	0.880	0.708	0.405
Succinic	0.348	0.862	0.734	0.370
Pyruvic	0.356	0.882	0.688	0.462
Lactic	0.344	0.868	0.708	0.424
Citric	0.364	0.892	0.876	0.514
Amino Acids				
Glycine	0.344	0.942	0.888	0.422
Alanine	0.366	0.878	0.818	0.388
Glutamatic acid	0.377	0.898	0.900	0.502
Tryptophan	0.348	0.846	0.814	0.464
Phenylalanine	0.360	0.875	0.718	0.443
Miscellaneous				
Hydrolysed Casein	0.375	0.734	0.688	0.418
Yeast Extract	0.354	0.600	0.578	0.348
Ascorbic acid	0.368	0.922	0.824	0.446
Urea	0.368	0.902	0.898	0.512
Uric acid	0.374	0.454	0.432	0.378

The results of the tests in cultures supplied with 1% CO_2 in air are presented in Table 4. The only definite acceleration of growth occurred in the sewage itself and in the fraction containing water soluble compounds. The acceleration was greater in the whole sewage than in the sewage which had been extracted with ether, possibly indicating that some but not all of the active materials had been removed by extraction with ether.

Included in these two series of experiments were two tests of the effect of fresh urine on the growth rate of *Chlorella pyrenoidosa*. Since a preliminary experiment indicated that this alga would not grow in fresh urine, the sample was diluted 1:10 with the inorganic medium before any of the cultures were made up. Thus the dilutions indicated in the table should be divided by ten to give the actual dilution. Urine gave good acceleration of growth in all cultures in which it was tested. Assuming a urine output of 1 quart per

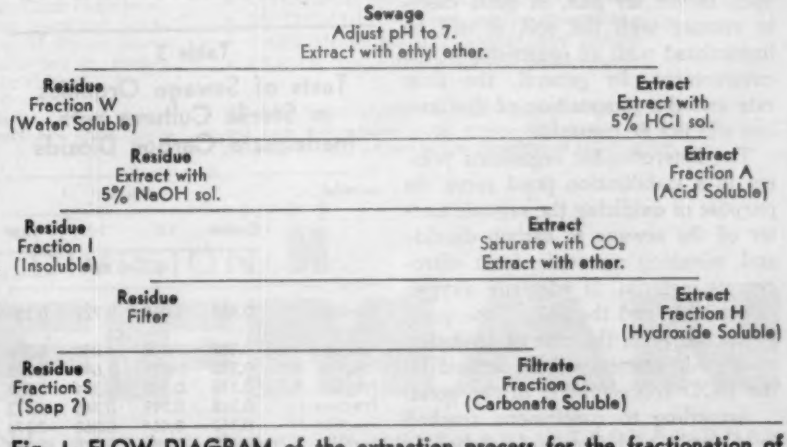


Fig. 1. FLOW DIAGRAM of the extraction process for the fractionation of the organic compounds of sewage.

Table 2

Tests of Organic Compounds in Sterile Cultures with Inadequate Carbon Dioxide Supply

Compound	Concentration			
	0	10^{-6}M.	10^{-4}M.	10^{-3}M.
	Growth Rate			
Glucose	1.400	1.490	1.460	1.465
Acids				
Formic	1.390	1.015	1.344	1.385
Acetic	1.410	1.180	1.380	1.390
Oxalic	1.460	1.410	1.385	1.395
Malonic	1.345	1.380	1.390	1.360
Tartaric	1.370	1.355	1.340	1.385
Succinic	1.400	1.385	1.385	1.385
Pyruvic	1.390	1.355	1.380	1.380
Lactic	1.360	1.360	1.380	1.355
Citric	1.385	1.370	1.370	1.390
Amino Acids				
Glycine	1.440	1.670	1.655	1.410
Alanine	1.385	1.595	1.610	1.510
Glutamatic acid	1.390	1.700	1.670	1.455
Tryptophan	1.360	1.655	1.670	1.420
Tyrosine	1.385	1.720	1.690	1.385
Miscellaneous				
Hydrolysed Casein	1.410	1.690	1.620	1.410
Yeast Extract	1.340	1.460	1.455	1.410
Ascorbic acid	1.385	1.390	1.380	1.410
Urea	1.385	1.860	1.860	1.390
Uric acid	1.370	1.440	1.410	1.390

person per day and a sewage flow of 80 gallons per capita per day, the urine present in sewage will be diluted about 1:400. The tests indicated that a dilution of 1:1000 urine stimulated the growth of *Chlorella* as much as did raw sewage alone.

Discussion

A stabilization pond is a type of continuous culture in which both heterotrophic and autotrophic organisms are present. Since the pond is open to the air and, in most cases, in contact with the soil, it will be innoculated with all organisms in the environment. In general, the flow rate and the composition of the sewage will not be constant.

The heterotrophic organisms present in a stabilization pond serve the purpose of oxidizing the organic matter of the sewage to carbon dioxide and releasing ammonia from nitrogenous material. If adequate oxygen is available and the pH of the pond is not too high, the rate of oxidation of organic matter will be limited by the BOD concentration of the pond.

According to conclusions reached by Oswald and Gotaas [1], carbon is most often the factor limiting the growth of algae in high rate stabilization ponds. In conventional oxidation ponds with long detention periods, the limiting factor may be either nitrogen or phosphorus, since there is more opportunity for carbon dioxide to be dissolved from the atmosphere. However, if the detention period of the pond is less than seven days, the concentrations of nitrogen and phosphorus in the pond will generally be greater than 1 mg/l. The very high pH values reached in high rate stabilization ponds is another indication that carbon dioxide is often limiting.

From the above considerations it is apparent that in a stabilization pond the growth rate of the algae most likely will be limited by the carbon dioxide concentration, at least when adequate light is available for photosynthesis. During periods of high light intensity, the photosynthetic rate will increase, increasing the rate of carbon dioxide uptake. The pH of the pond will also increase, but organic matter oxidation rate by the heterotrophs will decrease. It appears unfortunate that the period of greatest oxygen production due to high light intensity will coincide with decreased bacterial activity due to pH limitation.

The algae growing in a sewage stabilization pond will have contact with a certain amount of organic material in the pond. If the growth and metabolism of the bacteria present are limited by the pH of the pond, it is possible that appreciable concentrations of some organic compounds will accumulate. The results of these experiments indicate that *Chlorella pyrenoidosa*, a species of algae frequently found in sewage stabilization ponds, is able to utilize some of the organic compounds that are present in sewage. The results indicate that organic acids, some organic nitrogen compounds, and some vitamins will accelerate the growth rate of this alga, if the concentration of carbon dioxide in the culture is limiting. In a stabilization pond with a low CO_2 concentration, it is quite likely that the algae present will utilize organic matter from the sewage in addition to photosynthetically produced carbohydrates for the production of new cell material.

Table 3

Tests of Sewage Organics in Sterile Cultures with Inadequate Carbon Dioxide

Material	Dilution			
	Control	1:0	1:10	1:100
	Growth Rate			
Sewage	0.364	1.065	0.722	0.384
Urine (diluted 1:10)	0.348	1.100	1.030	0.866
Fraction W	0.372	0.889	0.646	0.397
Fraction A	0.375	0.368	0.354	0.368
Fraction I	0.368	0.298	0.348	0.372
Fraction H	0.362	0.464	0.368	0.374
Fraction S	0.365	0.386	0.375	0.354
Fraction C	0.352	0.512	0.408	0.366

Table 4

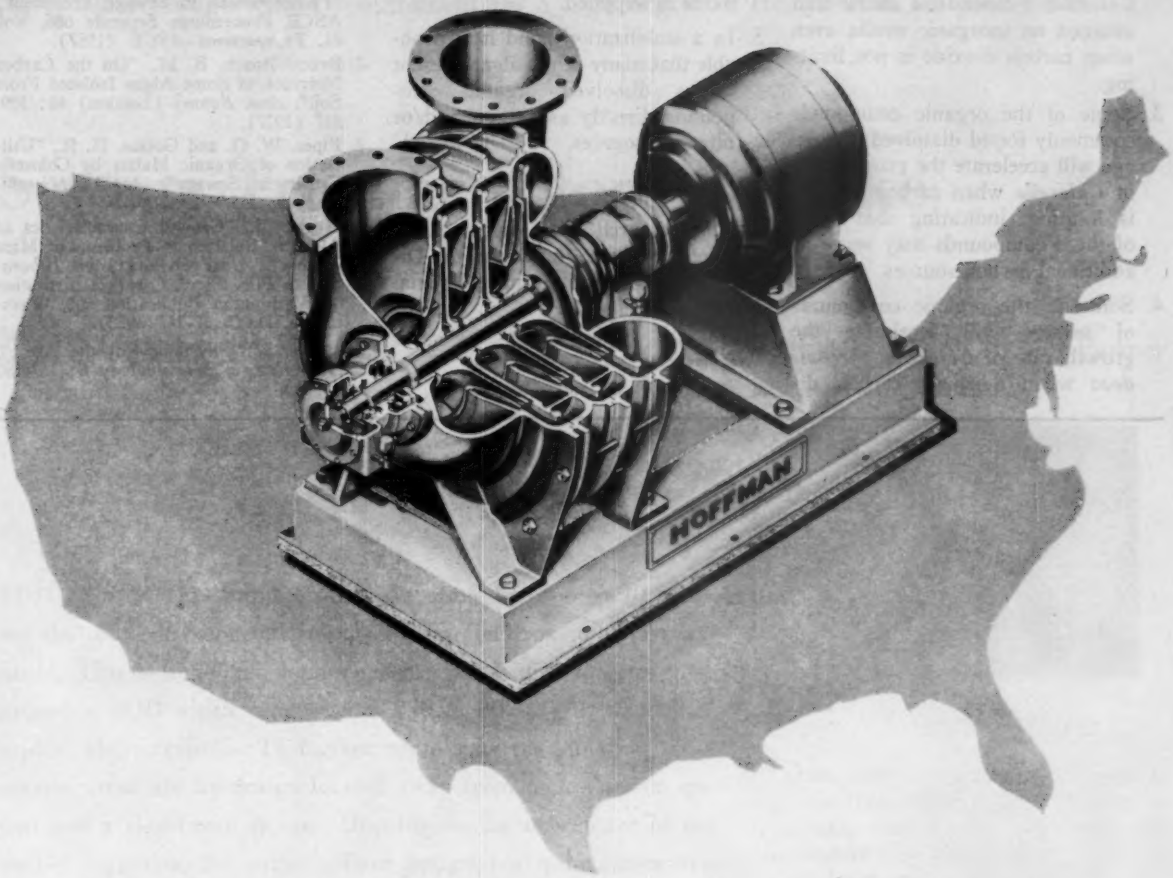
Tests of Sewage Organics in Sterile Cultures with Adequate Carbon Dioxide

Material	Dilution			
	Control	1:0	1:10	1:100
	Growth Rate			
Sewage	1.370	1.870	1.580	1.490
Urine (diluted 1:10)	1.385	2.240	2.080	1.880
Fraction W	1.390	1.680	1.520	1.410
Fraction A	1.370	1.360	1.370	1.385
Fraction I	1.420	1.120	1.240	1.320
Fraction H	1.360	1.470	1.380	1.395
Fraction S	1.380	1.310	1.360	1.420
Fraction C	1.390	1.370	1.410	1.360

Experimental results reported herein indicate that the organic compounds of sewage that are utilized by algae as additional sources of carbon are either in the water soluble group or in the base soluble group. The water soluble compounds that are active in the nutrition of the algae are most likely to be polyfunctional compounds such as carbohydrates and hydroxy acids or nitrogenous compounds such as urea, amino acids, and other products from the breakdown of proteins. The base soluble compounds are most likely to be carboxylic acid.

Conclusions:

1. Several types of organic compounds such as sugars, acids, amino acids, and some nitrogenous compounds will accelerate the growth rate of *Chlorella pyrenoidosa* when the rate of photosynthesis is limited by the concentration of carbon dioxide indicating that these compounds may be used as additional carbon sources.
2. Some organic nitrogen sources will accelerate the growth rate of



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Chlorella pyrenoidosa above that attained on inorganic media even when carbon dioxide is not limiting.

3. Some of the organic compounds commonly found dissolved in sewage will accelerate the growth rate of *Chlorella* when carbon dioxide is limiting, indicating that some of these compounds may serve as additional carbon sources.
4. Some of the organic compounds of sewage will accelerate the growth rate of *Chlorella pyrenoidosa* when adequate carbon dioxide is supplied.
5. In a stabilization pond it is probable that many of the algae present utilize dissolved organic compounds directly as carbon and/or nitrogen sources.

Acknowledgment

This research was supported in part by a research grant from the Divisions of Research Grants, National Institutes of Health.

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An unusual sewage with a requirement for a high degree of treatment is the problem in . . .

Sewage Treatment for Turnpike Service Areas

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EDITOR'S NOTE: With the turnpikes came the problem of treating the somewhat unusual sewage discharged from their service areas. This sewage has high concentrations of detergents and grease, a BOD which ranges from 250 to 380 mg/l, and other typical characteristics. To further complicate the situation these service areas are by design located away from both a sewer system and a significant stream. Drawing on the experience of the earlier turnpikes the author's firm designed a quite interesting little plant for the Ohio turnpike. All eight installations on this pike required a plant which would produce a highly treated effluent at minimum cost and with a minimum of supervision. It was necessary first to develop the design criteria for the plants as well as what type of plant to design. How these problems were met and the results of four years of operating experience is reported here.

■ ON THE OHIO TURNPIKE, 16 restaurant and service station areas have been provided. At each location, dual facilities have been constructed on each side of the highway. Each pair of restaurants and service stations is served by common water and sewerage systems. Thus there are eight separate systems, which are located at intervals of approximately 30 miles.

In selecting the route of the Ohio Turnpike, the bypassing of urban areas was a prime consideration, which is typical of all toll roads. This resulted in the restaurant areas being located, in most cases, considerably distant from municipal water supplies and sewage treatment plants.

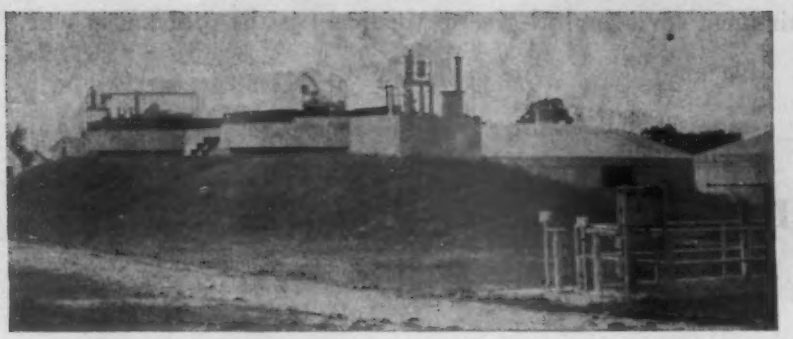
In two cases however, it was possible to make provisions to connect to municipal water systems, those of the Villages of Amherst and Swanton. At the six other locations, well water supply systems were installed. At no location was it possible to utilize a municipal system for sewage disposal. Thus, the construction of a sewage plant was required at each of the restaurant areas.

Because each restaurant area requires entrance and exit lanes on each side of the turnpike and because streams require bridges, the restaurant area locations were selected so that they would not be adjacent to major streams, thus eliminating the necessity for providing two additional lanes on bridge structures. This made necessary the installation of sewage treatment facilities providing a high degree of treatment in all cases. In seven of the eight locations, the receiving stream consisted only of a ditch or an intermittent stream.

Previous Experience

In 1954, when design of the Ohio Turnpike sewage treatment plants was undertaken, experience with facilities treating primarily restaurant wastes in the volumes contemplated was relatively limited. Comparable restaurant facilities had been installed on the Pennsylvania Turnpike and the New Jersey Turnpike. The original sewage treatment facilities in Pennsylvania, which were constructed in 1941, consisted of grease traps, septic tanks and sand filters. The original New Jersey installations consisted of septic tanks and covered leaching filters or tile fields.

All of the original installations had proved to be unsatisfactory and at approximately the time that the Ohio Turnpike plants were being de-



TWO OF THE COVERED TRICKLING FILTERS with the final pumping station and weir chamber in the foreground.

signed, the original Pennsylvania and New Jersey installations were in the process of being replaced or abandoned. Sand filters had been found to be unsatisfactory because the grease and detergents in the wastes had clogged the filters and necessitated frequent replacement of the top layers of sand. Odors, flies and freezing of the filters had also presented serious problems. Similar problems had been encountered at the New Jersey installations.

The difficulties experienced on the Pennsylvania and New Jersey Turnpikes were convincing proof that wastes discharged from the kitchens and toilet and wash rooms of the service areas were unlike normal sanitary sewage and that conventional methods of sewage treatment could not be utilized. It was also evident that sewage flow volumes could not be computed upon conventional per capita volume of flow bases.

Fortunately, the facilities on the Pennsylvania Turnpike were available to evaluate for the purpose of obtaining a basis of design. The Pennsylvania toll road was used instead of the New Jersey Turnpike, since it was felt that experiences on the Ohio Turnpike should be more similar to those on its neighboring highway than to the New Jersey data.

Design Criteria

A number of the original Pennsylvania stations were operating at maximum capacity and these had been used as a basis of study in the design of replacement facilities on the Pennsylvania Turnpike. Water supply records were used to determine flow data. The most pertinent data which came from the Pennsylvania studies were design flow criteria related to restaurant seating facilities. The average total flow from both restaurants and toilet and wash rooms was established as 350 gallons per day per counter seat and 150 gallons per day per table seat.

These quantities were used as the basis of design for the Ohio Turnpike facilities in addition to the new plants on the Pennsylvania Turnpike and were also used in the design of sewage treatment plants for the Northern Indiana Turnpike.

Since all of the eight service areas, each consisting of two restaurants and service stations, were to be identical in size and design, the eight sewage treatment plants were designed on the basis of the same number of table and counter seats and thus are identical in capacity. It was recognized that it was probable that some of the facilities would never reach the design capacity because of varying traffic volumes on the various sections of the toll road, but it was felt that this result was far better than to design the plants on the basis of an estimated traffic volume and to find one or more of the plants overloaded in a few years. Because of the type of design selected, oversizing of the units was relatively inexpensive and not detrimental to operation; expansion of the facilities would on the other hand be relatively costly.

With the Pennsylvania Turnpike results used as background data, the actual average flow selected for design purposes was 100 gpm, which included an approximate 20 percent factor of safety over the 350 gpd per counter seat and 150 gpd per table seat basis. Maximum-day average flows were assumed to be 175 percent of the average flow and peak flows were assumed to be 350 percent of the average flow. It was expected that there would be periods of time when there would be virtually no flow.

It was anticipated that BOD concentrations would be 500 mg/l, or somewhat over two times that of normal domestic sewage. The suspended solids concentration was assumed to be approximately that of normal sewage, or 250 mg/1, producing a population equivalent of 1,500 persons, at 0.20 pounds per capita per day. Among the most troublesome aspects of the sewage were the expected grease and detergents contents of the kitchen wastes. Concentrations of up to 100 mg/1 were anticipated in each of these two categories. Based upon the experiences in Pennsylvania, the sewage would also be much warmer than usual.

Treatment Method

In all considerations in determining the type of facilities to be installed the governing factor was that the sewage treatment plants should offer the least difficulty in operation, in order to minimize personnel requirements. Although the facilities were to be constructed by the Ohio Turnpike Commission, operation of the plants would be the responsibility of the restaurant concessionaire at each of the sites. Inasmuch as operation of the sewage treatment plant would represent an item of overhead for each concessionaire, it was only natural that manpower allocation to plant operation would be held to a minimum.

It was also considered that any operating difficulty encountered would almost certainly be multiplied by eight. For these reasons, although every consideration was given to minimizing initial cost without sacrificing any of the benefits to be achieved in operation, the factor of initial cost was deemed to be secondary to obtaining sewage treatment plants which could be operated easily and with a minimum of expense.

Three basic types of installations were considered. These were: Sand filters, Activated sludge and Trickling filters. In addition, consideration was given to utilization of separate sludge digestion versus modified Imhoff tanks.

Sand filters were discarded immediately because their ineffectiveness had been proved on the Pennsylvania Turnpike. It was conceded that, with adequate preliminary treatment and with modifications such as covering the filters, sand filters could perhaps have been utilized. However, since enclosed sand filters would be extremely expensive because of the large area involved and because sand filters do not offer much flexibility in operation, sand filters were deemed to be less desirable than trickling filters.

Activated sludge was discarded for several reasons. It was felt that activated sludge plants would require more control in operation, thus additional manpower requirements, over trickling filters. The problem of frothing was recognized and was not deemed to have been solved at the time, particularly considering the anticipated high detergents concentration. The ability of activated sludge to successfully treat the anticipated wastes was questioned. Activated sludge was rejected, however, somewhat reluctantly, since it was felt that the process could eventually be adapted to effectively handle service area wastes. However, the time to prove the ability of activated sludge was not available, nor was it deemed wise to construct eight "experimental" plants. Thus, activated sludge was also deemed less desirable than trickling filters and the latter were selected as the basic method of treatment.

It was also recognized that conventional standard rate trickling filters would not be completely satisfactory, inasmuch as they would not provide the solution to the filter fly and freezing problems; nor was it probable that they would provide sufficient BOD removals to satisfy the requirements of the receiving streams. For this reason, two-stage filters were selected, with recirculation at a fixed rate. Recirculation was to be applied to the primary filter through the primary settling facilities and directly to the secondary filter. In this way, continuous dosage of both filters would be obtained.

Trickling filters, however, would not solve the grease and detergents problem, so provision had to be included in the primary treatment facilities, or by pretreatment, to remove these constituents. Fortunately, by the fall of 1954, the new facilities on the Pennsylvania Turnpike had been in use for several months. These new facilities were being operated by introducing the raw sewage into the digester, or in reality to the digestion compartment of the mechanical Imhoff tank, thus providing anaerobic digestion of the grease and detergents.

THE CONTROL BUILDING WITH THE PRIMARY and final settling tanks to the right

The initial period of operation in this manner indicated that predigestion might completely eliminate surface scum from the primary settling compartment of the tank. This would greatly assist in odor control. In addition, the BOD concentration was being substantially reduced in the unit.

In order to minimize potential septic conditions in the settling portion of the tank, particularly during periods of low flow, recirculation of the primary filter effluent through the settling compartment was deemed necessary.

The combination of sedimentation, with pre-digestion, and two-stage trickling filters, with recirculation, seemed to offer the rugged process necessary to handle the concentrated and complex sewage anticipated; it offered simplicity in operation without the complexities of separate sludge pumping and without the necessity of pretreatment for grease removal. This process was, therefore, adopted.

Plant Units

The sewage treatment plant constructed at each of the eight service areas consists of the following units:

Table I

Design Criteria

Average Flow	—100gpm.
Recirculation Flow	—100gpm.
5-Day BOD	—500mg/l. and
Suspended Solids	—250mg/l (1,500 persons.).

Control Building, housing the comminutor, raw sewage pumps, recirculation pumps, wet wells and chlorination facilities. The building superstructure is of brick, designed similar to the main service plaza buildings. In all cases, the sewage treatment plants are in close proximity to the restaurant areas.

Two Clarigesters, each 18 ft in diameter, which are operated in parallel. The settling compartments are 7 ft deep and the digestion compartments, 14 ft deep. Each unit is provided with a wood cover to minimize any possible odor problem and to maintain warm temperatures during cold weather.

Two Trickling Filters, each 48 ft in diameter, by 6 ft depth of filter media, operated in series. Each filter is covered with a reinforced concrete dome, with glass block skylights and ventilated through a louvered gravity ventilator. Although it was believed that odors from the trickling filters would not present a significant problem, the domes were provided to eliminate any possibility of odors and to prevent freezing of the filters. By covering the filters from view, the domes also improved the sewage treatment plant appearance and removed the psychological problem of imaginary odors being experienced by people who have only to see sewage being distributed on filters to smell disagreeable odors.

Final Settling Tank, 16 ft sq, by 10.75 ft total water depth. The tank is constructed with a hopper-bottom. Sludge is drawn through a telescoping sludge valve into a sludge box and is returned to the raw sewage wet well.

Chlorine Contact Tank, 8 ft by 5 ft, by 7 ft water depth, for chlorination of the plant effluent. Chlorine is ap-

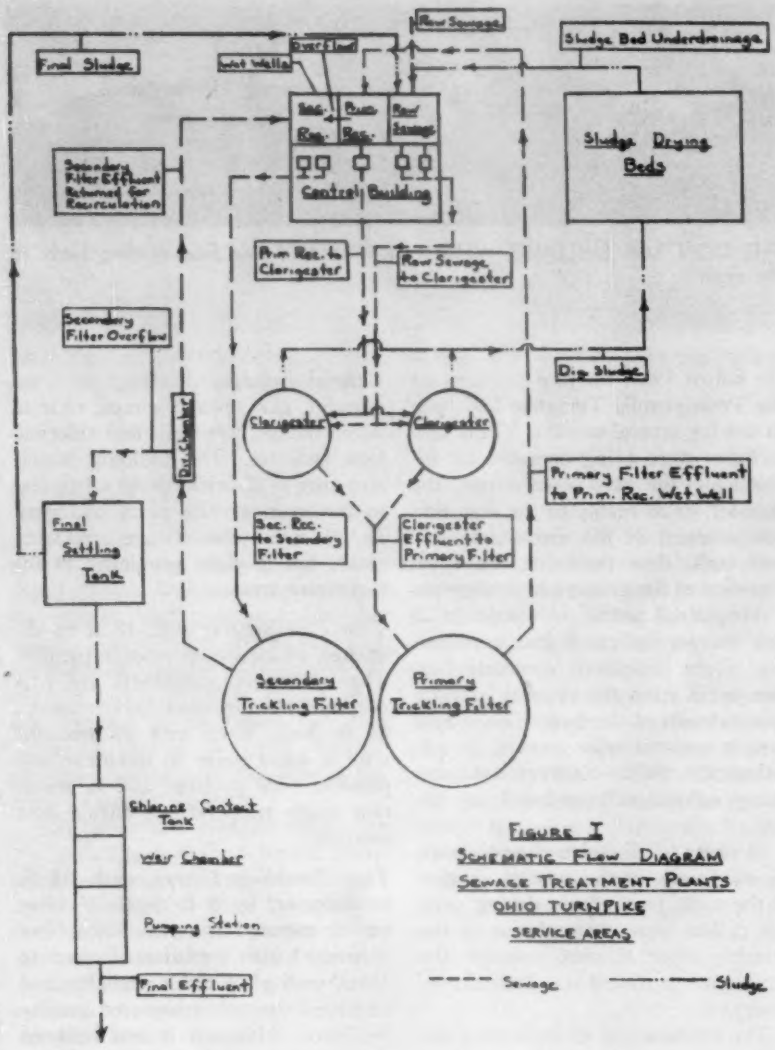


FIGURE I
SCHEMATIC FLOW DIAGRAM
SEWAGE TREATMENT PLANTS
OHIO TURNPIKE
SERVICE AREAS

plied by means of a gas chlorinator, which also applies chlorine, if required, into the raw sewage pump discharge line for pre-chlorination.

Weir Chamber. A V-notch weir is provided on the plant effluent with a hook-gage, but a meter is not included. Sewage flows are determined from the service area water meters.

Final Pumping Station. Because of variable topographic conditions, three of the sewage treatment plants provide for pumping of the plant effluent to the receiving stream and five provide for pumping of sewage to the final settling tanks.

Two Sludge Drying Beds, each 20 feet by 40 feet; open beds. Sludge bed underdrainage is returned to the raw sewage wet well.

The raw sewage pumps are of 100 gpm and 300 gpm capacities. The final pumps are of the same capacities. Operation of both the raw sewage pumps and final pumps is automatically controlled by the sewage levels in the wet wells.

The primary recirculation pump is 100 gpm in capacity and is manually started and stopped.

The secondary recirculation pumps are of 200 gpm and 300 gpm capacities. The 200 gpm pump is manually operated and the 300 gpm pump is interlocked with the 300 gpm raw sewage pump, so that when the latter pump is in operation, the 300 gpm secondary recirculation pump also operates. The two 300 gpm pumps are also interconnected so that the recirculation pump can be used as a raw sewage pump in case of emergencies. All pumps are vertical centrifugal pumps.

When the 100 gpm raw sewage pump is in operation (Fig 1) both the discharge from this pump and the 100 gpm primary recirculation pump reaches the primary filter. At the same time, the 200 gpm secondary recirculation pump discharges to the secondary filter. Thus, the recirculation ratio on both filters is 1:1. However because the volume of application is fixed, the recirculation ratio exceeds 1:1 when average raw sewage flows are less than 100 gpm and is less than 1:1 when flows exceed 100 gpm.

Sewage reaches the sewage treatment plant by gravity from both the restaurant areas, passes through the comminutor and enters the raw sewage well (Fig 1).

The raw sewage pumps discharge to either of two outlets in the digestion compartment or to an outlet in the flow compartment of each combined settling digestion tank. The effluent of these units flows by gravity to the primary filter.

The primary filter effluent flows to the primary recirculation wet well, from which sewage is recirculated by the primary recirculation pump to the flow compartment of each of the settling digestion tank and thence to the primary trickling filter.

Sewage overflows from the primary recirculation wet well to the secondary recirculation wet well at a rate equal to the raw sewage flow. From the latter wet well, the secondary recirculation pumps discharge the sewage to the secondary filter.

The secondary filter effluent flows to a diversion chamber, from which sewage overflows to the final settling tank at a rate equivalent to the raw sewage flow. The remainder returns to the secondary wet well. From the final settling tank the plant effluent flows to the chlorine contact tank and thence to the receiving stream.

On the basis of tables 1 and 2 it was estimated that the plant effluent would have a BOD concentration of approximately 20 mg/1.

The construction cost of each of the sewage treatment plants varied with local conditions, including rock excavation in some cases. The exact

cost of each plant is not known since lump sum bids were received for the facilities including the water supply systems. However, the estimated cost of each sewage plant was approximately $200,000, including the collection sewers from the restaurant areas.

Operating Results

Each of the sewage treatment plants has now completed four years of operation. Table 3 includes a complete analysis of operating results for the year 1957, which is typical of the four years of operation.

The results are interesting in a number of aspects. The average flow for the eight plants was 0.034 mgd, or 24 gpm. This is substantially less than the design flow, which indicates that all plants are operating at only a fraction of capacity and that the recirculation ratio is on the average of approximately 4:1 on the primary filters and 7:1 on the secondary filters.

Complete daily flow results are not available, but at one site the maximum average daily flow was 370 percent of the yearly average and the minimum 20 percent of the yearly average. The average raw sewage BOD was 250 mg/1, or one-half of the design concentration, although at one plant the concentration was substantially higher, 384 mg/1. The average raw sewage suspended solids was 223 mg/1, or approximately the design concentration.

Because of the relatively low loadings on the plants, removals are substantially higher than anticipated. The average BOD in the effluents was 5 mg/1, varying from 1 mg/1 to 10 mg/1. The average suspended solids concentration in the effluents was 11 mg/1. All plants produced an effluent high in dissolved oxygen, the five plants reporting averaging 8.8 mg/1. Removals averaged 98 percent BOD and 95 percent for suspended solids.

Some of the plants are operated with raw sewage being discharged to the flow compartment of the settling digesting tank, others with the discharge to the digestion compartment. The difference in results obtained from the two methods does not appear to be significant at the present time.

Analyses are not made for grease

Table 3

OHIO TURNPIKE SEWAGE TREATMENT PLANTS—OPERATING RESULTS—1957

Location Near	West Unity	Swanton	Woodville	Clyde	Amherst	Brecksville	Freedom	New Springfield	Average
Sewage Flow-mgd									
Average Day	0.024	0.034	0.035	0.041	0.037	0.030	0.032	0.039	0.034
Maximum Month	0.041	0.055	0.054	0.069	0.055	0.047	0.059	0.065	0.056
Minimum Month	0.014	0.013	0.023	0.023	0.028	0.019	0.015	0.026	0.020
Maximum Day	0.054	0.126	—	0.102	0.071	—	—	—	—
Minimum Day	0.006	0.007	—	0.014	0.014	—	—	—	—
BOD mg/l									
Raw Sewage	244	239	217	320	384	196	192	205	250
Effluent	5	6	10	4	9	2	1	1	5
Suspended Solids mg/l									
Raw Sewage	240	258	126	244	304	210	199	204	223
Effluent	12	12	5	15	31	3	4	3	11
DO mg/l									
Raw Sewage	1.8	2.0	4.5	5.0	3.4	—	—	—	3.3*
Effluent	8.1	8.1	8.3	10.4	9.0	—	—	—	8.8*
Loadings lb/dy BOD									
Raw Sewage	48.5	67.6	63.3	109.0	119.3	49.0	51.1	66.8	70.9
Effluent	1.0	1.7	2.9	1.4	2.8	0.5	0.3	0.3	1.4
Suspended Solids									
Raw Sewage	48.0	72.9	36.8	83.3	93.8	52.5	53.1	66.5	63.1
Effluent	2.4	3.4	1.5	5.1	9.6	0.7	1.1	1.0	3.1
Population Equiv. of Raw Sewage									
BOD	290	405	379	653	716	294	306	400	425
Suspended Solids	240	364	184	415	469	262	265	332	315
Removals									
BOD	98	97	95	99	98	99	99	99	98
Suspended Solids	95	95	96	94	90	99	98	99	95

* 5-Plants Only #BOD at 0.167 lb/cap/dy; Suspended Solids at 0.20 lb/cap/dy

Table 2
Unit Loading

Combined Settling Digesting Tank

Digestion Capacity—4.7cf/capita,
Surface Overflow Rate—568 gpd/sf,
Digestion Capacity—4.7 cf/capita,
Total Detention (Including Digestion Compartment)—400 minutes;

Primary Trickling Filter

Hydraulic Loading—159 gpd/sf;
BOD Loading—55.5 lb/1,000 cf/dy (1.5 lb/cy/dy);

Secondary Trickling Filter

Hydraulic Loading—159 gpd/sf;
BOD Loading—14.4 lb/1,000 cf/dy (0.39 lb/cy/dy);

Final Settling Tank

Detention—127 minutes,
Surface Overflow Rate—841 gpd/sf;

Chlorine Contact Tank

Detention—21 minutes

Sludge Drying Beds

Capacity—1.1 sf/capita.

and detergents concentrations, but these constituents have not produced significant problems.

Odor problems have not been reported and pre-chlorination is not utilized in any of the plants. A chlorine residual is maintained in the plant effluents in all cases.

Sludge is withdrawn from the digestion compartment approximately five times per year. It is reported to be well-digested and dries readily.

A minimum amount of attendance is required at the plants. The plants are operated by employees of the restaurant concessionaires, but operators from nearby municipalities, certified by the Ohio Department of Health are retained as supervisors.

The initial four years of operation have produced evidence that the operating results of the plants have satisfied the initial expectations and that the plants should continue to produce acceptable effluents well into the future.

Equipment Suppliers

Dorr-Oliver, Incorporated—Clarigester mechanisms and rotary distributors;
Chicago Pump Company—Comminutors (5 sites);
Inflilco, Incorporated—comminutors (3 sites);
Weinman Pump Manufacturing Company—sewage and recirculation pumps;
Fisher and Porter Company—chlorinators (6 sites);
Wallace and Tierman, Incorporated—chlorinators (2 sites);
Bowerston Shale Company—filter underdrains.

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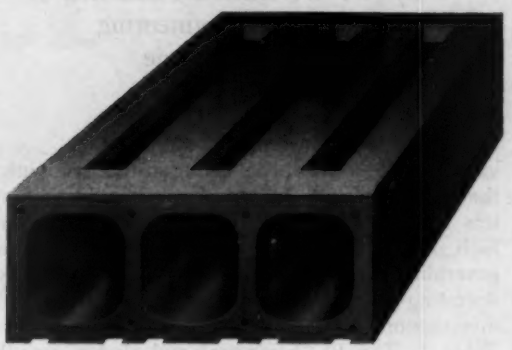
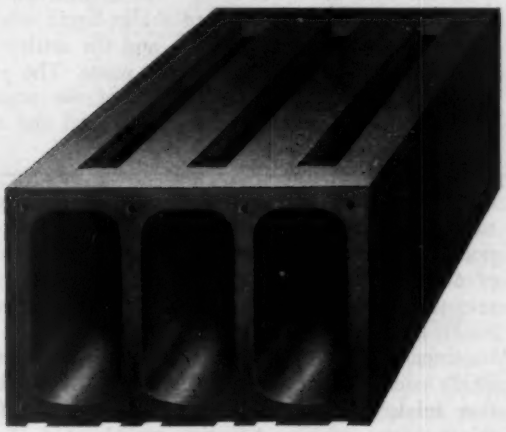


Tri-Filter #5

Standard-Rate

Size	4¾" x 11¾" x 15½"
Weight per unit	28 lb.
Weight per sq. yd.	196 lb.
Aeration per sq. ft.	39.3 sq. inch
Aeration %	27.3%
Runoff sq. inch/lin. ft.	30.9 sq. inch
Runoff %	55.4%



Tri-Filter #8

Hi-Rate

Size	7½" x 11¾" x 15½"
Weight per unit	41 lb.
Weight per sq. yd.	288 lb.
Aeration per sq. ft.	39.3 sq. inch
Aeration %	27.3%
Runoff sq. inch/lin. ft.	52.4 sq. inch
Runoff %	59.3%

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Theory and Practice of Activated Sludge Process Modifications

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■ THE PAST DECADE has seen increased interest in the application of the activated sludge process to the treatment of sewage and industrial wastes. In order to increase the efficiency of the process and reduce capital and operating costs, various process modifications have been developed. Research advances on the mechanism of the process have led to improved design methods. It is the purpose of this paper* to review these recent developments as they apply to several modifications of the activated sludge process and to discuss recent performance data from these processes.

Mechanism of the Activated Sludge Process

When an organic waste is contacted with biological sludge, BOD is removed by several mechanisms. Suspended and finely divided solids are removed by adsorption and coagulation. A portion of the soluble organic matter is rapidly removed by absorption and stored in the cell as a reserve food source. Additional dissolved organic matter is progressively removed during the aeration period resulting in the synthesis of sludge and the production of carbon dioxide and water. The rate of BOD removal after initial absorption depends primarily upon the concentration of BOD to be removed and the concentration of active sludge solids. The reactions involved in the removal of soluble BOD from solution during bio-oxidation can be interpreted as a three-phase process:

a. An initial removal of BOD on contact of a waste with a biologically active sludge which is stored in the cell as a reserve food source.

b. Removal of BOD in direct proportion to biological sludge growth.

c. Oxidation of biological cellular material through endogenous respiration.

At high BOD concentrations the rate of BOD removal is independent of concentration and is directly proportional to the concentration of activated sludge present. BOD removal under these conditions is exposed by Equations 1 and 2, Table 1. At low BOD concentrations, the rate of removal becomes BOD concentration dependent and removal becomes directly proportional to both the concentration of activated sludge solids and the BOD remaining in solution. Wuhrmann, et al,[18] has shown that the rate of removal of simple specific compounds is usually linear with time and sludge solids concentration to very low substrate levels, less than 1 ppm. The kinetics of these reactions are explained by the laws governing enzymatic reactions. The removal of phenol by activated sludge appears to follow this linear relationship. The complex nature of sewage and many industrial wastes causes a decreasing BOD removal rate as oxidation proceeds since the various waste components differ in the ease with which they are oxidized. In some waste oxidation systems this results in long detention period requirements for high BOD removal. The mathematical relationships governing BOD removal and sludge growth for various operating conditions have been formulated by several investigators[1 2 3 4]. The relationships are summarized in Table 1. The BOD removal and sludge growth relationships are schematically shown in Figure 1.

Four modifications of the biological sludge process will be discussed in this paper namely, the conventional activated sludge process, the contact-stabilization process, total oxidation and the aerated lagoon.

Conventional Activated Sludge

In the conventional activated sludge process, waste is mixed with biological sludge and aerated for a predetermined period. The aerated sludge-liquid mixture is then separated by sedimentation and the settled sludge returned for admixture with fresh waste. The aeration period is determined by the BOD of the waste, the concentration of mixed liquor solids and the desired BOD removal efficiency.

In the case of low BOD wastes, e.g., sewage, paper mill wastes, etc., the process usually operates over the range B-C (Fig. 1). This requires an aeration detention period of t_1 and results in a sludge accumulation of ΔS_2. The mathematical relationships governing BOD removal under these conditions is shown by Equations 3—7 in Table 1. Conventional activated sludge treatment of domestic sewage usually operates over a BOD loading range of 0.2—0.4 lbs BOD/day/lb aeration solids[5]. For aeration solids levels of 2000 ppm this requires aeration detention periods of 4—6 hours. A major part of the BOD is removed in the first few minutes of aeration by biosorption and flocculation. Oxidation and synthesis occur during the remainder of the aeration period. Since oxygen utilization is intimately associated with BOD removal and sludge growth, the oxygen demand rate curve will approximately follow the BOD removal curve. In the conventional process this results in a high initial demand rate followed by a rapid decrease to the endogenous rate toward the end of the aeration period. For average sewage strengths the oxygen uptake rate will vary from 60 ppm/hr at the head end of the aeration tank to approximately 15 ppm/hr at the outlet end. Tapered aeration is necessary to follow this demand rate curve.

*Presented at 1960 Annual Meeting, Michigan Sewage and Industrial Wastes Assoc.

Table I
Summary of Biological Oxidation Kinetics

Condition	BOD Removal Equation	Remarks
1. High BOD Wastes	$2.3 \log\left(1 + \frac{aL_r}{S_o}\right) = K_s t$	applicable when the initial BOD/sludge solids ratio exceeds 2; applies only when BOD removal is independent of BOD concentration (usually) at BOD levels above 200-300 ppm.
2. High BOD wastes	$\frac{L_r}{t} = \frac{K_s S_a}{a}$	applicable when initial BOD sludge ratio is less than 2. Same limitations as equation (1)
3. Low BOD wastes	$\frac{L_r}{L} = \left(1 - e^{-K_s S_a t}\right)$	describes course of BOD removal for single substrates with initial BOD's less than 300 ppm.
4. Complex wastes	$L = L_a e^{-(K_s)_a t} + L_b e^{-(K_s)_b t} + L_c e^{-(K_s)_c t}$	
5. Complex wastes	$-\frac{dL}{dt} = \frac{K_s}{(1 + mt)} L$	Equations 4, 5, and 6 estimate BOD removal from complex waste substrates in which the removal rate decreases with time or concentration
6. Complex wastes	$-\frac{dL}{dt} = K_s \left(\frac{L}{L_a}\right)^n L$	
7. Complete mixing	$\frac{L_r}{L} = -\frac{dl}{dt}\left(\frac{t}{L_a}\right)$	defines removal from completely mixed aeration tanks

Nomenclature: a — fraction of BOD removed converted to sludge
K_s — sludge growth rate constant
K_s — BOD removal rate constant
L_a — initial BOD concentration
L_r — BOD removed
m, n — retardent constants
S_a — average sludge solids concentration
S_o — initial sewage solids concentration
t — time

Process modifications such as step aeration in which the sewage is added to the aeration tank in increments down its length or complete mixing in which the sewage is added along the length of the aeration tank will equalize the oxygen demand throughout the aeration tank at its mean rate. This will insure more uniform distribution of oxygen and maintenance of dissolved oxygen.

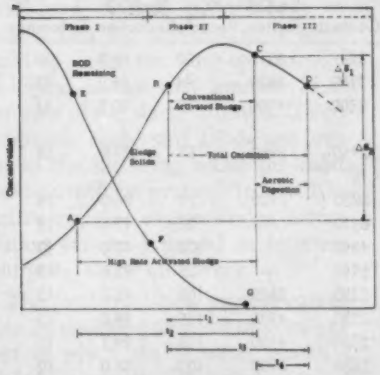

Fig. 1. SCHEMATIC OF the activated sludge process.

Mixed pulp and paper mill wastes have been treated by the conventional process at the West Virginia Pulp and Paper Company, Covington, Va.[6] for several years. Recent operating data are summarized below:

Average Performance for Nov.-Jan., 1960
Activated Sludge Plant—
West Virginia Pulp & Paper Co.,
Covington, Virginia

Flow, mgd	21.0
BOD, ppm	188
Suspended solids, ppm	122
lbs BOD applied/day/lb aeration sludge	0.67
Mixed liquor suspended solids, ppm	2280
Sludge volume Index	286
Recycle sludge (%)	30
Aeration Detention, hrs.	2.3
% BOD removal	84
lbs N/100 lbs BOD removed	3.4
lbs P/100 lbs BOD removed	0.7

BOD removal from this waste follows a retardent reaction whereby 65—75 per cent of the BOD is rapidly removed from solution in the first hour of aeration and the remainder at a progressively decreasing rate. BOD removals in excess of 85—90 per cent consequently require long aeration detention periods. The mean oxygen utilization was found to vary from 35.3 ppm/hr/1000 ppm sludge at the influent and of the aeration tank to 8.9 ppm/hr/1000 ppm sludge at the effluent end. BOD removal relationships from a mixed pulp and paper mill waste are shown in Figure 2.

In the case of high BOD wastes (BOD> 500 ppm), the process operates over the range A—C (Fig. 1). For high BOD removals the detention period is increased to t_2 and the excess sludge accumulation to ΔS_2. Down to a limiting concentration of BOD, the BOD removal is approximately linear with sludge concentration and time, (E-F) Fig. 1; Equations 1 and 2, Table 1. Below this BOD concentration the rate of removal is concentration dependent. The oxygen utilization rate will remain at a constant or a slightly increasing value over the range E—F. Below point F, Figure 1, the uptake rate will rapidly decrease and level out at the endogenous rate. In the treatment of pharmaceutical waste[7] the BOD removal rate averaged 200 ppm/hr/1000 ppm sludge to a limiting concentration of approximately 400 ppm. At lower concentrations the removal rate progressively decreased. In the treatment of phenolic wastes with an initial phenol concentration of 800 ppm, by the activated sludge process, the removal rate of phenol averaged 0.75 lbs phenol removed/day/lb aeration sludge. This removal

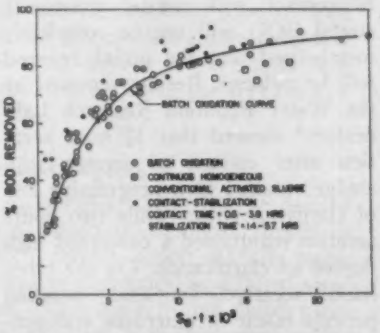
% BOD REMOVED
BATCH OXIDATION CURVE
BATCH OXIDATION
CONTINUOUS HOMOGENEOUS CONVENTIONAL ACTIVATED SLUDGE
CONTACT-STABILIZATION
CONTACT TIME = 0.5 - 3.0 HRS
STABILIZATION TIME = 1.4 - 5.7 HRS

Fig. 2. BATCH AND continuous oxidation relationships at low BOD concentrations.

was linear with time and aeration solids. The sludge accumulation in the process was 0.16 lbs VSS/lb phenol removed.

Oxygen utilization rate will remain at a constant or a slightly increasing value over the range E—F. Below point F, Figure 1, the uptake rate will rapidly decrease and level out at the endogenous rate. In the treatment of a pharmaceutical waste[7], the BOD removal rate averaged 200 ppm/hr/1000 ppm sludge to a limiting concentration of approximately 400 ppm. At lower concentrations the removal rate progressively decreased.

Contact Stabilization

When a high percentage of the BOD is rapidly removed by biosorption after contact with well aerated activated sludge, the contact—stabilization process can be advantageously employed. In this process waste is aerated with stabilized sludge for a short contact period, usually 30—60 minutes. The mixed liquor is then separated by sedimentation. The settled sludge is transferred from the clarifier to a sludge stabilizer where aeration is continued to complete the oxidation and to prepare the sludge for BOD removal from fresh incoming waste. The process is schematically illustrated in Figure 3.

When the BOD removal rate is too low to attain the desired overall BOD removal in a short contact period, the aeration contact period can be extended to attain the additional desired removal. This additional removal is indicated in Figure 3.

The magnitude of the initial removal is dependent on the conditions of the sludge when it is in contact with waste and on the waste characteristics. If the sludge has had an insufficient period of aeration prior to contact with waste, previously stored BOD will not be completely metabolized and the initial removal will be reduced. Results reported by the Water Pollution Research Laboratory[8] showed that ½ hour aeration after contact of sewage with sludge resulted in a progressive loss of clarifying power while two hours aeration maintained a continued high degree of clarification. On the other hand, excessively long sludge aeration periods result in extensive endogenous respiration and resulting loss in BOD removal capacity of the sludge. Wuhrmann[9] demonstrated a rapid reduction in the removal rate of lactose by activated sludge with sludge aeration periods up to 216 hours. The relation between sludge aeration or stabilization time and BOD removal for various contact periods is shown in Figure 3. The data in Figure 3 were obtained by aerating sludge with a mixture of domestic sewage and textile mill waste for 15 minutes, separating the sludge, and aerating the sludge with waste for 0.25, 1.0 and 1.5 hours after the indicated stabilization periods. It is apparent from Figure 3 that for a contact period of 0.25 hours, a stabilization period of 2—6 hours is necessary to maintain the BOD removal capacity of the sludge. Increasing the contact period to one hour permits some oxidation of the absorbed BOD and reduces the stabilization requirement to 1 hour.

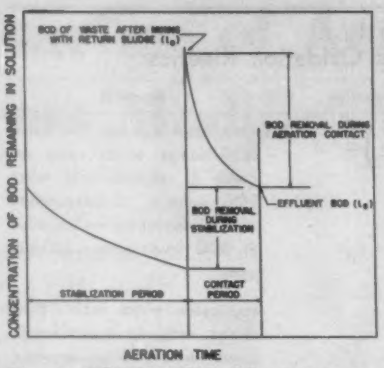
CONCENTRATION OF BOD REMAINING IN SOLUTION
BOD OF WASTE AFTER MIXING WITH RETURN SLUDGE (L_0)
BOD REMOVAL DURING AERATION CONTACT
EFFLUENT BOD (L_e)
BOD REMOVAL DURING STABILIZATION
STABILIZATION PERIOD
CONTACT PERIOD
AERATION TIME

Fig. 3. SCHEMATIC OF contact-stabilization process.

The required stabilization period will depend on the magnitude of initial BOD removal and on the contact detention period. Increasing the contact period permits some oxidation of absorbed organics and reduces the required stabilization period. A substantial increase in the contact period will permit complete oxidation of the absorbed organics and eliminate the need for stabilization. This is then a conventional activated sludge process. Increasing the concentration of mixed liquor suspended solids will decrease stabilization requirements for the same BOD loading since the BOD removal per unit sludge mass will be reduced. Under these conditions less time is required for the oxidation of the absorbed BOD in the stabilization tank.

The contact stabilization process has been employed for the treatment of domestic sewage at Austin, Texas[10] and Bergen County, New Jersey[11]. Pilot plant and full scale plant studies were reported employing this process for the treatment of cannery wastes[12]. High BOD reductions have been reported in the application of this process to the treatment of pulp and paper mill wastes[13]. BOD reductions in excess of 85 per cent have been found in the treatment of a mixture of domestic sewage and textile wastes[14]. The performance of the contact-stabilization process treating these wastes is summarized in Table 2.

Total Oxidation

Total oxidation, by definition, is a process so designed that the biological sludge produced by synthesis is consumed by auto-oxidation. In or-

Table 2
Performance of the Contact-Stabilization Process

		Detention, hrs.		Suspended Solids, ppm				
Waste	BOD	Contact	Stabilization	Contact	Stabilization	% Recycle	% BOD Reduction	Reference
Sewage	264	0.24	1.60	3251	5218	100	02.5	—
Sewage	108	1.30	4.25	2239	8629	44	88.0	11
Sewage	210	0.18	1.00	2500	4500	100	90.0	11
Sewage and Textile Mill	225	0.60	5.50	2950	6950	67	77.0	14
Sewage and Textile Mill	320	1.10	3.30	3200	7900	71	86.0	14
Pulp & Paper	249	0.50	3.70	6360	—	25	72.0	13
Pulp & Paper	191	1.00	4.0	4642	—	100	87.0	13
Pulp & Paper	218	2.00	2.0	5980	—	25	93.0	13
Tomato cannery	412	0.80	1.6	2250	3600	100	85.0	12
Tomato cannery*	450	0.35	1.65	2250	4500	125	84.0	12
Tomato & apple	492	1.00	2.00	2500	4400	100	89.7	12
Peach & tomato	740	0.65	1.30	3600	5900	100	58.0	12

*Aero-Cycleter Stabilizer Pilot Plant

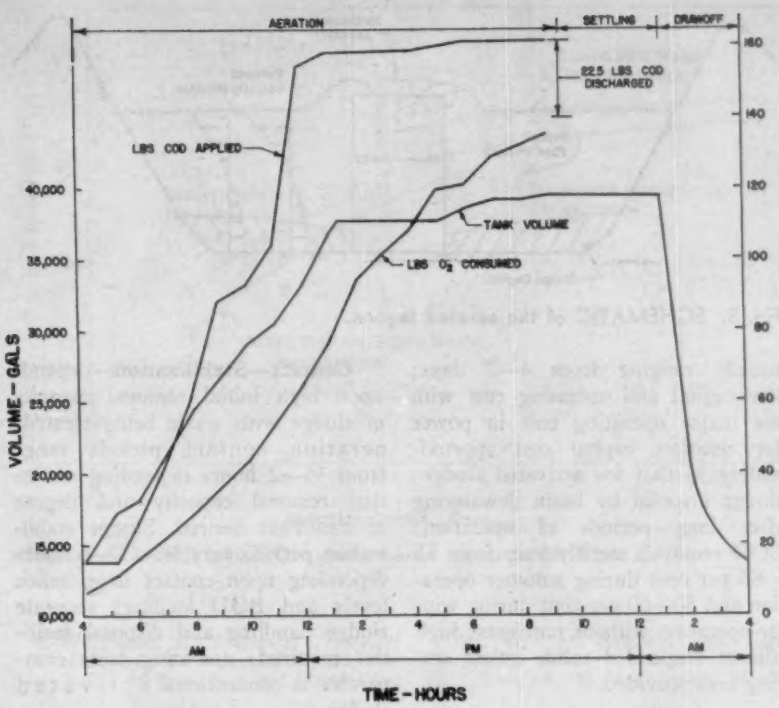

Fig. 4. BATCH TREATMENT of dairy wastes.

der to accomplish this oxidation, the aeration detention period must be increased from t_1 to t_3 (Figure 1). The process then operates over the range B—D and the sludge accumulation, Δ s theoretically approaches zero.

In practice, it has been shown that the auto-oxidation of biological sludge does not follow first order kinetics, but rather follows a retardent reaction in which the rate of oxidation decreases with time or concentration. This is because of the various cellular constituents differ in their ease of oxidation. A portion of the cellular material is highly resistant to oxidation and results in an accumulation in the process. McKinney[15] and Kountz et al[16] have indicated that the non-oxidizable solids build-up from the auto-oxidation of biological sludge may amount to 25 per cent of the sludge formed. If non-oxidizable suspended solids are present in the incoming waste the solids build-up will be greater. In small installations, this excess sludge accumulation can be removed at intermittent intervals by tank truck.

The total oxidation process can either be designed as a continuous system in which the aeration detention period is usually 24 hours or as a batch fill and draw system. The batch system is most adaptable to industrial wastes of sewages in which the total waste flow is received over 8—12 hours. The operation of a batch system involves aeration, settling and decantation from a single tank. This sequence of operations for a dairy waste is shown in Figure 4.

Since the detention period required for BOD removal is considerably less than that required for auto-oxidation, the tank volume will be controlled by the sludge oxidation rate. The following procedure can be employed to determine design criteria.

The sludge balance in the aeration tank can be approximately expressed by the relationship:

$$\Delta S = aL_r - b \int a \qquad (8)$$

in which ΔS = increase in biological sludge solids in lbs/day.

a = fraction of BOD synthesized to sludge. This usually varies from 50—75 per cent of the 5-day BOD removed.

L_r = BOD removed, lbs/day.

b = mean rate of auto-oxidation, fraction per day. For soluble substrates such as dairy wastes, b, will average between 15—25 per cent per day at 25°C. Wastes containing suspended solids of a low oxidation rate such as domestic sewage may have endogenous rates of 6—12% per day.

S_a = average mixed liquor suspended solids, lbs.

Equation 8 does not consider the inert fraction of sludge which is not oxidized in the process. In the total oxidation process $\Delta S \cong 0$ and Equation (8) becomes:

$$aL_r = bS_a \qquad (9)$$

The quantity of sludge which must be maintained under aeration in order to approach total oxidation is

$$S_a = aL_{r/b} \qquad (10)$$

The application of Equation 10 can be illustrated by the following example:

Design a total oxidation plant to treat 26,000 gpd of a dairy waste containing 161 lbs COD over a period of 17 hours. The mean auto-oxidation rate of the sludge is 24 per cent per day. The COD reduction is 90 per cent.

COD removed/day = 0.90 x 161
= 145 lbs/day

Equilibrium quantity of sludge

$\Delta S_a = aL_r - bS_a$

$\Delta S_a = 0$

$aL_r = bS_a$

If the constant a for dairy waste is 0.5 and if aeration proceeds for 17 hours then

$$(0.5)\ (145) = 0.24 \frac{17}{24} - S_a$$

$S_a = 430$ lbs

If the sludge occupies 0.8 cu ft/lb the required sludge volume is

(0.8) (430) = 344 cu ft

The waste volume is 26000/7.48
= 3500 cu ft

Sludge free board = 172 cu ft

Total tank volume = 4016 cu ft

Since in the total oxidation process the sludge produced by synthesis is consumed by auto-oxidation, the oxygen requirements are greater than the conventional process. For the case of complete sludge oxidation the total oxygen requirements will approximately equal the ultimate BOD.

Aerated Lagoons

An aerated lagoon can be defined as a lagoon of significant depth in which aerobic conditions are maintained by mechanical or diffused aeration. While the activated sludge process employs high biological solids and short aeration periods, the aerated lagoon requires long detention

periods and employs very low solids concentrations. The aerated lagoon is schematically shown in Figure 5. The purification capacity of an aerated lagoon is comparable to that in natural streams since the solids and turbulence levels are of the same order of magnitude[17].

Since the biological sludge solids concentration is very low, BOD removal is primarily a function of detention time. Data obtained from several experimental lagoon installations are shown in Figure 6. Performance data are summarized in Table 3. The oxygen requirements in an aerated lagoon are directly proportional to the BOD removed. Because of the long retention period, much of the sludge produced by synthesis is consumed by auto-oxidation. Several systems studied showed the oxygen requirement to vary from 0.9—1.2 times the 5-day BOD removed.

Oxygen is transferred to the lagoon contents from the atmosphere through surface turbulence and from mechanical or diffused aeration systems. In most cases approximately 25 per cent of the required oxygen is transferred through the surface and the remainder by the aeration system. It is the writer's opinion that mechanical aeration systems afford a more economical initial installation and a reduced maintenance cost. Most mechanical surface aeration systems on the market today can be expected to transfer 2.5—3.5 lbs O_2/hp-hr. Based on an oxygen demand rate of 1.1 lbs O_2/lb BOD removed and 2.5 per cent surface aeration, the power requirements for lagoon aeration may be expected to vary from 0.24 —0.33 hp/lb BOD removed.

Summary

Biological waste treatment facilities cover a wide spectrum of process applications, from the aerated lagoon with long retention periods and low solids to the high rate activated sludge process with short aeration periods and high aeration solids. The selection of method depends primarily on the characteristics of the wastes, geographical location and the effluent requirements of the regulatory agency. The advantages and disadvantages of the process modifications described in this paper are summarized below:

Aerated Lagoons—require large land areas with retention periods usually ranging from 4—7 days; low capital and operating cost with the major operating cost in power for aeration, capital cost approximately ⅔ that for activated sludge; sludge disposal by basin dewatering after long periods of operation; BOD removals usually vary from 75 —85 per cent during summer operation and 50—60 per cent during winter operation without nutrients; high effluent suspended solids unless settling area provided.

Conventional Activated Sludge—compact installation with retention periods varying from 2—6 hours for low BOD wastes and up to 24 hours with high BOD wastes. High capital and operating costs; separate sludge handling and disposal facilities required; high BOD and suspended solids removals in summer and winter.

Contact—Stabilization—depends upon high initial removal capacity of sludge with waste being treated; aeration contact periods range from ½—2 hours depending on initial removal capacity and degree of treatment desired. Sludge stabilization periods vary from 2—6 hours depending upon contact time, solids levels and BOD loading; separate sludge handling and disposal facilities required; operating costs comparable to conventional activated sludge.

Total Oxidation—requires long aeration periods to oxidize biological sludge. BOD removals comparable to conventional activated sludge; minimal sludge handling facilities; economically favorable for low waste volumes.

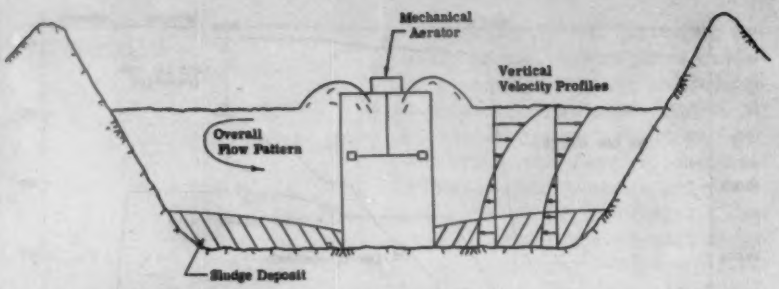

Fig. 5. SCHEMATIC of the aerated lagoon.

Table 3
Aerated Lagoon Performances

Waste	ppm	Det'n days	Temp. °C	% Reduction
Pulp & paper (without nutrients)	210	1	27	33
	250	2	23	42
	250	2	20	48
	200	3	31	72
	250	4	15	64
	290	4	20	59
	260	4	25	62
	210	4	30	81
Cannery (without nutrients)	580	5	25	71
	550	4	25	65
	890	3	26	60
	840	2	26	59
	605	1	24	43
Board mill (without nutrients)	457	3	23	81.3
	465	5	"	87.4
	452	7	"	89.1
Board mill (with nutrients)	457	3	23	78.0
	465	5	"	86.5
	452	7	"	88.7

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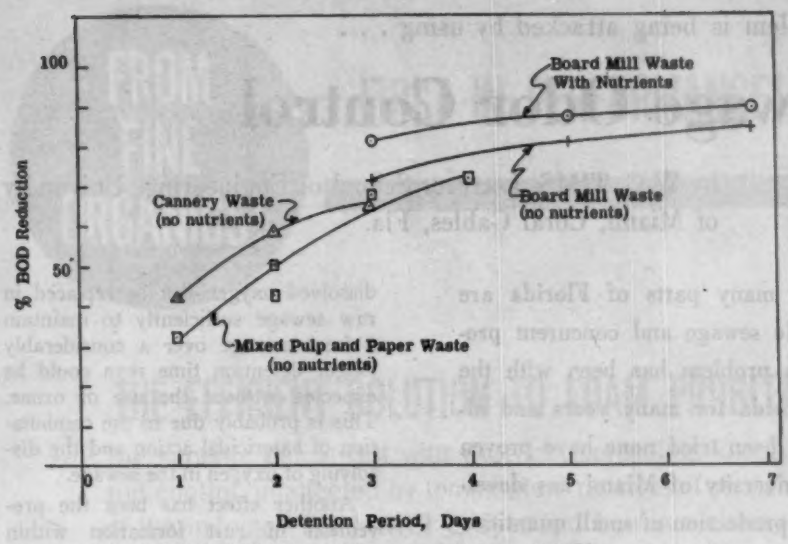

Fig. 6. AERATED LAGOON performance (temp = 25°C).

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A different septic sewage problem is being attacked by using . . .

Ozone for Sewage Odor Control

by W.C. TIMS, Lecturer School of Engineering, University of Miami, Coral Gables, Fla.

EDITOR'S NOTE: Conditions in many parts of Florida are ideal for the development of septic sewage and concurent production of hydrogen sulfide. This problem has been with the sewage treatment profession in Florida for many years and although many control methods have been tried none have proven too successful. Research at the University of Miami has developed an economical method for the production of small quantities of ozone. The use of this oxidizing agent has been quite effective in the control of the odor and corrosion problem resulting from the generation of hydrogen sulfide. The details for the testing program are presented in this article.

■ HIGH CONCENTRATION of organic and inorganic sulfur compounds in some of the ground water in Florida coupled with a high temperature induced year round incubation period, flat sewer grades and long detention periods result in the break down of these compounds. The resulting hydrogen sulfide is the cause of serious corrosion and deterioration problems at treatment plants and pumping stations as well as odor problems of considerable magnatude.

Development and Testing

A somewhat new approach to the control of this problem was developed at the John Mantell Sanitary Engineering Laboratory of The University of Miami. This laboratory which is located at the Coral Gables Sewage Treatment plant has carried out the reasearch and development on a small inexpensive unit to produce between twenty and 150 grams of ozone O_3 per hour. These units have been field tested for over two years at sewage lifts stations, in trickling filters, sludge pits and other sources of odors in and around sewage treatment plants. Good success has been reported under adverse conditions. It has been found that by careful installation of the unit the dissolved oxygen can be replaced in raw sewage sufficiently to maintain a fresh sewage over a considerably longer detention time than could be expected without the use of ozone. This is probably due to the combination of batericidal action and the dissolving of oxygen in the sewage.

Another effect has been the prevention of rust formation within building by keeping walls, machinery and iron work dry and free of condensation without harmful effects from oxidation within switch gear or wiring. This situation results from the dehumidifying effect of operating the units in a closed building. This secondary benefit is sufficiently attractive that in several cases it is actually the primary benefit desired.

When installed in the air duct under trickling filters these units have been successful in controlling odors and in preventing or reducing filter flies.

Studies are under way utilizing these units to produce ozone for decolorization and sterilization of water.

An ozone generator of this type is produced under the name Oxiconverter by Kellum Brothers Engineering, Ft. Lauderdale, Fla.

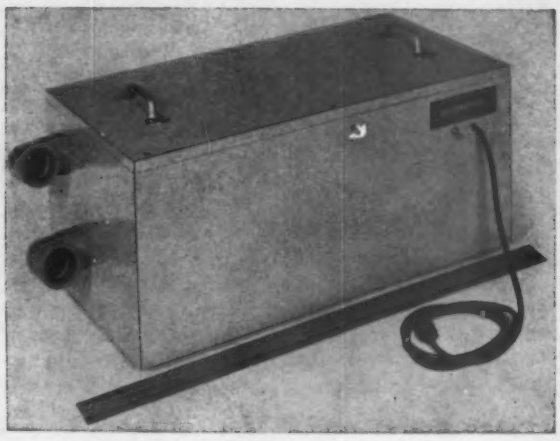

FIG 1 THE OXICONVERTER UNIT

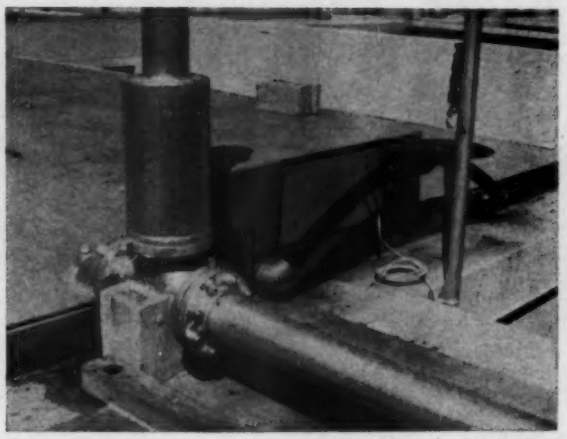

FIG 2 THE UNIT at the grit chamber at the North Miami, Fla. sewage treatment plant.

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Oceanic wastewater disposal requires study of many factors including . . . . .

Wind Drift in the Waters of the Southern California Shelf

by ROBERT E. STEVENSON, Director of Inshore Research Allan Hancock Foundation University of Southern California.

ED. NOTE: Increased use of the ocean for wastewater disposal makes mandatory the study of major ocean currents, tides, density variations, earth rotation and winds. This report summarizes the role of wind in moving water over southern California's mainland shelf.

■ THE SUCCESS of any ocean effluent outfall depends primarily upon the movements of the receiving water. Proper engineering design can aid by increasing the initial dilution which is important in reducing bacteria numbers. Even so, if the ocean receiving the effluent has characteristics which result in little dispersion of the sewage field, or currents that carry the discharged material rapidly to shore; then no amount of engineering short of complete treating facilities can assure proper disposal.

In California, only the new five-mile outfall of the City of Los Angeles and the proposed outfall of the City of San Diego have been designed following adequate oceanographic surveys. All other outfalls that are functioning within the standards established by regional Water Pollution Control Boards, are doing so by fortuitous placement. There are several that are not operating with efficiency and have, or will, require expensive modification. It is obvious, thus, that any discharging agency should know as much about the receiving waters as is possible within the bounds of their prevailing economic situation.

The most practical information from the standpoint of the discharging agency is the structure and patterns of the local ocean currents. A general knowledge of the grand current systems in the vicinity is of little value because (1) the major currents rarely carry water over the shelf, (2) the water over the shelf differs by varying degrees from oceanic water, and (3) the shelf area, when compared with the magnitude of the ocean, is minute. Therefore, we find that winds, tides, and minor density variations are the important forces in generating lateral water motion. Friction from the sea floor and barrier effects from the coast become significant to the extent that the complexity of water movements can only be detailed by the acquisition of empirical data.

It is recognized that often, perhaps usually, a discharge agency may find it disadvantageous, for one reason or another, to initiate an oceanographic investigation of any sort. But because of the necessity of knowing at least the elements of the current system in the receiving waters, some method need be known to obtain information quickly and easily.

Studies by two organizations and a few individuals of the nearshore currents in southern California have resulted in data that show a definite relationship between the wind and local surface currents. It is rare that information of the local winds is not available. Thus, by applying wind data, some understanding of the local current patterns may be learned. This, then, will determine the magnitude of the further work that will, of course, be necessary prior to final location and design of the outfall.

With these various considerations in mind, I have collected data into this report which I feel will be useful to those involved in ocean disposal. I must add this caution, however, that forces other than the wind are important in controlling current systems and that from the local winds one can gain only part of the total current pattern.

General Statement

Ocean currents are conveniently divided into three groups: (1) currents which are related to the distribution of density, (2) currents which are the direct result of wind stress on the sea surface, and (3) currents associated with tides and internal waves (Sverdrup, Johnson & Fleming, 1946).

The large scale currents of the oceans belong to the first class, such as the Gulf Stream, Kuroshio, California Current, and others equally as well known. All of these transport great volumes of water, and their courses remain seaward of the mainland shelves. Off southern California eddies or gyrols from the California current approach the coast but lose their identity over the shelf.

Effective water motion over the shelf is developed primarily by wind stress on the sea surface, and in some areas by the tide wave. Where the wind prevails in one direction over large areas, the resulting wind drift of surface waters will be uni-directional. Tide currents, on the other hand, run alternatingly in opposite

directions, and thus are of no direct importance to the circulation of ocean waters. Over the shelf, and especially near shore, winds are more often than not controlled by local heating and cooling, so that the surface drift due to wind stress is neither constant nor in the same direction. In such areas alternating tide currents could be of greater significance than wind-driven currents.

Any motion in the atmosphere or ocean must take into account the effect of the earth's rotation (Coriolis force). In nearly all other problems of mechanics, Coriolis force can be neglected because other forces acting are much greater, but in the ocean it becomes significant. The deflection due to Coriolis effect is proportional to the speed at which the mass travels, is directed at right angles to the velocity, and to the right looking down current in the northern hemisphere.

Wind Currents

The stress that the wind exerts on the sea surface leads directly to the development of a shallow wind drift.

Subsequently, the water transported by the wind drift alters the distribution of density which develops corresponding currents. The latter process is most significant in oceanic areas where prevailing winds dominate for sufficient time for currents to develop. Near coasts, where the winds are variable and often diurnal in nature, density distribution changes so rapidly that permanent current patterns are never established, although one system may dominate all others. In the near shore area, the density distribution rarely dominates the water structure to the extent that currents result. There are instances where density currents are present, but mostly the wind drift is the outstanding feature of water motion.

When the wind exerts a stress on the sea surface, which sets the surface layer in motion, this moving layer of water exerts a stress on the next underlaying layer, and so on. These latter stresses are appreciable even when the velocity difference between adjacent layers is small, because of the high value of eddy viscosity. Ekman (1902) examined theoretically the wind drift, assuming eddy viscosity to be constant, and noted that in the northern hemisphere the wind drift at the surface is directed 45° to the right of the wind. With the increasing depth of water, the angle between the current and the wind increases, and the velocity of the current decreases. If the velocity at equal intervals of depth is represented by an arrow of the correct direction and appropriate length corresponding to the speed, the arrows will form a spiral staircase, the steps of which become narrower as the depth increases.

Obviously a depth always exists at which the current flows in a direction opposite that of the surface current. At this depth the velocity has decreased to a small fraction of its value at the surface, and below this depth, the currents are negligible. Ekman called this depth the *depth of frictional resistance*. The depth of frictional resistance increases with the increasing wind velocity and with decreasing latitude. The relations between depth of frictional resistance, D, wind velocity, W, and latitude, a, are expressed approximately by $D = 7.6W \sqrt{\sin a}$. The depth is obtained in meters when the wind velocity is given in meters per second. From Ekman's calculations the velocity of wind drift at the sea surface is $V = 0.013\ W \sqrt{\sin a}$. Such theoretical wind drift can develop only in the open ocean in regions where the wind blows in the same direction and with a constant velocity over wide areas. Near coasts where neither directions nor velocities prevail for more than a few hours and where the barrier effect of the coast becomes significant, marked deviations occur in wind drift patterns.

Secondary effects of the wind may, on occasion, be important in shelf waters. Consider a wind in the northern hemisphere blowing parallel to a coast which is on the right hand of an observer with his back to the wind, and assume that the density of the water increases with depth, primarily because the temperature decreases. The direct effect of the wind leads to the transport of light and warm surface water shoreward. But because the coast represents an obstruction to the flow, the light and warm water "piles up" against the coast. At some distance offshore denser and colder subsurface water must rise to replace that which has been carried toward the coast. The distribution of density is thus altered, and, as a secondary effect, a current develops which flows in the direction of the wind according to the rule that the lighter water shall be on the right hand side of the current. Such a distribution of density and subsequent current develops along parts of the southern California coast, when southeast winds preceding frontal storms blow for 24 hours or more (Stevenson and Gorsline, 1955). Once the system is formed or a steady state is reached, the density pattern and currents may persist for 24 to 72 hours following the storm.

If the coast lies to the left of the wind direction the light and warm surface water is transported seaward, and is replaced by denser and colder subsurface water next to the shore. This process, known as upwelling, again leads to an altered distribution of density to which a current flowing in the direction of the wind corresponds. Experience has shown that such upwelling is restricted to shallow depths, and over the Los Angeles and Orange County shelf its effect can be traced to about 200 feet (Stevenson and Gorsline, 1955). The intensity and gradient followed by upwelling water varies with the strength of the winds and the width of the shelf. Along the Newport-Huntington Beach coast in Orange County, California, it is a minor feature due to the wide shelf, but it exists more often than not, varying in intensity and extent as the dominant westerly winds vary. When rhythmic land and sea breezes occur, upwelling patterns and subsequent currents often "pulsate"; the lower pulse being during the land breeze hours.

Current Viscosity

In dealing with the movements of effluent discharged from ocean outfalls we are primarily concerned with the movement of the upper two to four feet of the ocean surface. This is where the low density effluent is concentrated and where the high bacteria numbers occur. In addition, because of the density difference, the effluent is more readily affected by wind drift. We must not, nevertheless, restrict our study to this thin layer, for the motion of the underlying water also has varying effects on the surface drift.

Theoretical analyses of water motion over continental shelves have been few in number. Various phases

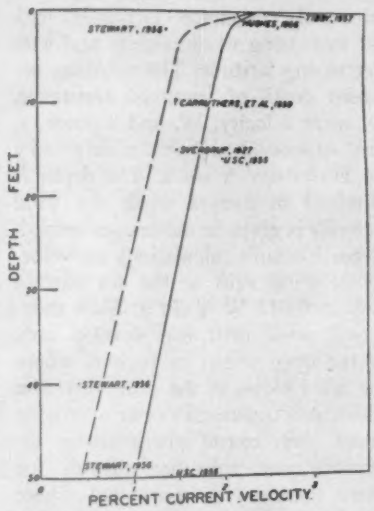
of the problem have been reported on by Hidaka (1954), Arthur (1954), and Leipper (1957). None of these aid in determining the velocity of water movement. One paper applicable in this respect is by Fleming (1938), in which current velocities developed by tidal action are discussed, Since less than 20 per cent of lateral motion over the southern California shelf is due to tidal conditions, even that report, though of considerable interest, does not allow determination of current velocities.

We must, therefore, turn to empirical studies of water movement in nearshore waters. In each the drift of various objects has been noted and the relationship to the wind calculated. Most of the objects have been artificial, and placed by the observers into the water at specific times and places. Sverdrup (1927), however, made his evaluations by studying the drift of pack ice during the "Maud" expedition in the Arctic Ocean. Over a period of many months he concluded that the pack drifted at a velocity of 1.5 per cent that of the wind. This figure has been used since that time by casual observers to denote the expected velocity of surface currents and/or objects other than ice in other areas. Such a use and an assumption must be viewed with suspicion, because, as Sverdrup noted, many factors effected the flow of ice; i.e., pressure by adjacent ice packs, grounding of the ice, and the convergence of ice packs. He did establish, though, a definite relationship between the wind and the surface drift of the ocean.

In the Dover Straits, Carruthers, Lawford, and Veley (1950) found that the water movement was 1.5 per cent of the wind travel at a depth near ten feet. This figure is backed by about three years of continuous current and wind measurements taken from a lightship; so the accuracy of the conclusions is considered good. Although this information is certainly more applicable than that of Sverdrup's because the area is a strait, it cannot be considered as truly representative of an open shelf.

A complete discussion of the literature is not made here in regards to the problem of wind drift versus wind velocity, for much is not applicable. But, from the following work we note there to be a considerable conformity. This is particularly true in studies carried out by Stewart (1956) Tibby (1957), and by the Staff at the Hancock Foundation, University of Southern California, in 1956, for their areas of investigation were over the southern California shelf. The work by Bowden (1953) and Hughes (1956) shows differences mainly because the regions studied were in the open sea where the water motion is unrestricted.

Surface Motion:—Hughes conducted his field study in the Atlantic west of the British Isles. Unweighted plastic cards were dropped from aircraft about 140 miles at sea. During the period of drift, analyses were made of the wind system to determine the direction and velocity of the surface air flow. The results showed that cards travelled at 2.2 per cent the velocity of the wind, and there was no deflection of their course from the wind direction. Although this was a noteworthy study, the results must be weighed against the method employed. First, there were no wind observations; the direction and velocities were computed from daily weather charts as gradient winds. These must certainly differ to some extent from the actual winds at the sea surface. Secondly, because unweighted cards were used, it is likely that at higher wind velocities (greater than Beaufort Force 4) the cards were blown from one wave crest to another. Thus, rather than representing the water movement of the upper two or three feet of the ocean, the directions and velocities of the cards were more representative of a thin surface film (say, one or two centimeters). Hughes, therefore, considered that the wind factor was probably too high, and the drift angle closer to one or two degrees. Furthermore, the factors cannot be applied near coastal boundaries, due to the lack of uniformity in the wind systems, the presence of gradient currents nearshore, the effect of the tide, and barrier effects of the shoreline. Even so, the implication that the uppermost water moves directly with the wind is significant.



CURVES SHOWING relationship between percent current velocity and water depth.

An interesting conformity with the results of Hughes is found in Tibby's (1957) analyses of hundreds of drift card paths in Santa Monica Bay near Los Angeles, California. The plastic cards were released at pre-selected stations, ranging from three to seven miles from shore at more or less monthly intervals from September 1955 through June 1956. These cards were weighted so that they floated upright with about five inches of their length below the surface, and two inches above. Thus, the wind was virtually ineffective in moving the cards, and their drift represented the movement of at least the upper six inches, and probably the one or two feet, of the sea. The resulting wind factor averaged 2.5 per cent of the wind velocity observed at the Los Angeles International Airport. It is unfortunate that the research vessel, Velero IV, was required to leave the area each time cards were dropped. Whenever observations were made in Santa Monica Bay aboard the ship, and these were checked against those from the airport, neither velocities nor directions were comparable. Directions were usually in the same quadrant, but the velocities were higher on shore in the morning and lower during the afternoon and early evening. It is likely that if wind velocities at sea could have been obtained for the period of drift, Tibby's factor would have been close to the one determined by Hughes.

In a drift card study conducted at Newport from July 14 to September 5, 1958 (Stevenson, 1958), a number of the cards were recovered offshore. These gave most valuable data, for there was no lag time in their recovery. The calculated velocities,

then, should be compatible with the actual current flow of the ocean during the inclusive hours between release and recovery.

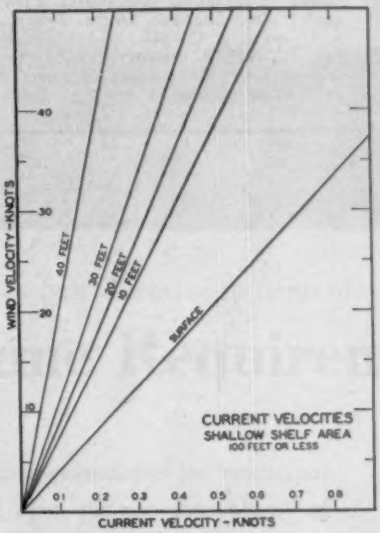
In comparing the highest velocities of the cards with the concurrent winds, we note that when the surface current was 0.2 knot or greater, and the winds greater than 7 knots for two hours or more, the wind/current factor was comparable to those recorded by Tibby and Hughes. However, on several occasions, when the currents flowed at velocities greater than 0.2 knot, the winds were blowing at only from 1 to 6 knots. Obviously, the wind/current factor was much higher than 3.0. From this we must assume that in some areas forces other than the winds can generate currents with significant velocities. These forces are noted in the absence of brisk winds, but need not be restricted to such periods. More likely, winds of sufficient velocity override the forces. As an example, morning winds on August 26, 1958, were slow, but a current of 0.22 knot was flowing *toward* shore. Later in the day, when the wind velocity increased to 10 knots, a current of 0.27 knot flowed *along* the coast; *with the wind* (Stevenson, 1959).

From these three investigations involving the uppermost surface of the sea, it is believed that one can reasonably consider the upper six-inches of the ocean over an open shelf to move more or less directly down wind at a velocity of 2 to 3 per cent that of the wind. This is, of course, after steady state conditions have been reached.

Subsurface Motion:—Bowden measured wind currents in the North Atlantic by towing electrodes through rectangular courses. By this method he considered that the water motion in the upper 50 fathoms was measured. During a radical wind shift, when wind velocities ranged from 18 to 30 knots, the current direction changed and became steady within three hours, and never exceeded 0.3 knot. The magnitude of the drift was about 1 per cent of the wind, speed, and 18 degrees to the right of the wind direction.

When considering water motion over the shelf below the surface layer, the work of Stewart (1956) and by the Staff at the Hancock Foundation in 1955-56 is most applicable. Stewart worked generally in water less than 100 feet deep. The drift studies by the scientists at the Hancock Foundation were conducted in deeper shelf waters. In each case the techniques were similar. Both groups used surface and subsurface drogues, which were followed for rather short periods of time (1 to 10 hours), and the drogue positions were accurately determined. Observations of wind and water temperatures were gathered during the times of drift.

Surface and subsurface drogues were released from the Velero IV in Santa Monica Bay in the spring and summer of 1956. The computations made by the writer from the data in the subsequent report (Stevenson, Tibby, and Gorsline, 1956)



CURRENT/WIND diagram for determining shallow shelf area current velocities.

show that at a depth of 15 feet the average current/wind factor was 2 per cent, and at a depth of 50 feet the factor was 1.4 per cent. The drogues were all released in 300 feet of water, some seven miles from shore in the center of the bay. All drifted more or less shoreward, and as they were in the water between 0900 and 1600 hours, the sea breeze was the main motive force.

Several score drogue paths were plotted from the year's study conducted by Stewart in the shelf waters off Point Loma and Imperial Beach near San Diego, California. Drogues were released in groups with at least one surface float and another below the thermocline at an average depth of 5 to 60 feet. Because the depth of water at the release point was usually 100 feet or less, many of the subsurface drogues grounded nearshore. The average current/wind factor at Point Loma was 1.4 per cent, and at Imperial Beach, 1.3 per cent. Subsurface currents were also lower in the latter area, where at a depth of 40 feet the factor was 0.4 per cent. In the waters off Point Loma the water at 50 feet had an average velocity of 0.6 per cent that of the wind.

Both sets of data are quite reasonable when the oceanographic and geographic conditions in the two areas of investigation are taken into account. In Santa Monica Bay the drift paths were always in water deeper than 100 feet, four to seven miles from shore, and progressed shoreward. As would be expected the velocities in nearer shore areas are less than those farther offshore. Drift angles also differ. In Santa Monica Bay drift in the upper layers averaged 18 degrees to the right of the wind. Whereas, in the San Diego area the average was 44 degrees at Point Loma and 39 degrees off Imperial Beach. In both velocity factors and drift angles, the barrier and deflective effect of the coast on nearshore water movement is clearly shown.

In Figure 1 the data considered have been plotted and two best fit curves drawn. There is no assurance that these curves should parallel each other or that they are straight line functions between 2 and 50 feet. Nevertheless, their application to currents and winds in the shelf area of southern California has been confidently made when the direction of air flow is judicially considered. For example, winds blowing from the east, southeast, or south can develop velocities noted from the lower of the two curves. Such winds will normally result in a current directed shoreward and the shoaling bottom and barrier effect of the shore result in reduced velocities. Winds from all other directions result in velocities noted from the upper curve. To facilitate determinations, a current/wind diagram is presented in Fig 2.

Resume

Over the mainland shelf of southern California where the major water movements of the ocean dissipate, or

enter the area infrequently, the wind attains a dominant roll in moving the water, especially the shallow wind drift.

The wind exerts its greatest influence on the surface of the sea so that here the current flows at an average of 2.5% of the wind velocity. No deviation of current direction from that of the wind usually occurs, except in the very nearshore region where the shore influences both the direction and velocity of the water flow.

The effect of the wind is readily apparent to depths of 50 feet, but the reaction of the water to the air stream decreases appreciably. Wind/current factors average 1.3% at 20 feet and 1% at 50 feet.

Over a wide shelf the wind, undermost conditions, is the significant factor in developing currents. Primary and secondary effects of the tide are important in certain areas. These latter forces must be determined by detailed surveys, whereas a general concept of the wind's influence may be gained by the use of wind data alone.

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The efficiency of this digester is best discussed in terms of . . .

Digester Volume Requirements

by LEONARD L. LANGFORD
Eastern Sales Manager
Pacific Flush Tank Co.,
Port Chester, N. Y.

EDITOR'S NOTE: Digester volume requirements for municipal sewage sludge stabilization depend upon the use the volume of sludge is to serve and the effectiveness of this service. The volume requirement for a proposed facility is directly related to construction costs, and the efficient use of the volume provided is related to operating costs. The objective is, of course, to make these two costs as low as possible.

The author discusses the digester volume requirements including capacity for sludge storage, supernatant and actively digesting liquors. The advantages of a proprietary method of mixing which will allow for classification of bottom solids and excellent volatile solids reduction are discussed.

■ THE INCREASED EFFICIENCY of a biological process is only made possible by complying with the understood theoretical demands of the process. In the case of mesophilic digestion, an adequate supply of acceptable food must be made constantly available to the process organisms, the organisms must be maintained in a liquid media and a suitable temperature range of about 95 to 100°F must exist.

To meet these requirements or demands calls for rigid process control which has not always been available. Prior to 1925, solids reduction of sorts was obtained with no more control than is presently afforded by septic or Imhoff tank operation.

By 1926, John R. Downes had initiated the idea of maintaining a constantly positive digester gas pres-

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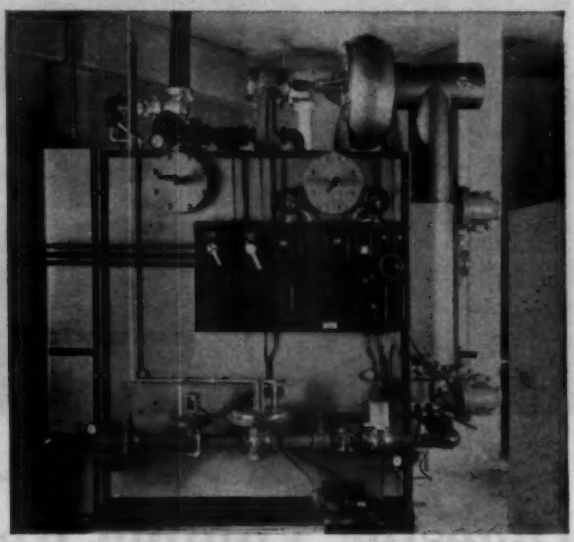

Digester Heaters and Heat Exchangers —External heaters for digestion tanks allow complete accessibility in a compact unit of high thermal efficiency. Raw sludge or a mixture of raw and recirculated digester contents is heated as it passes through the unit. With external heating, the problems of heating coils within the tanks (caking, corrosion) are avoided. Cleaning and maintenance are simplified. Detailed drawings and estimated digester heating loads furnished on request. Submit the number of digesters, tank capacities and quantity of raw sludge.

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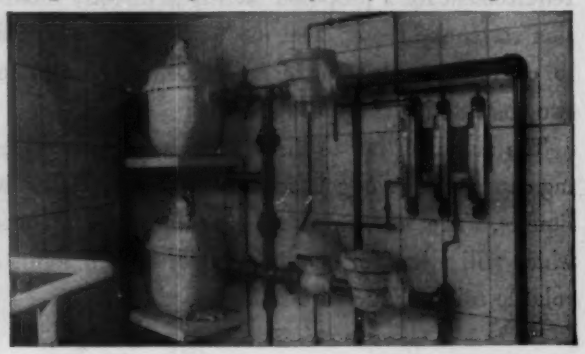

Gas Safety Equipment —A number of devices, each designed to perform its function in a gas utilization system with the greatest possible protection against explosive or burning mixtures of sludge gas and air: flame traps, pressure reliefs, pressure reliefs combined with flame traps, flame cells, waste gas burners, drip taps, accumulators and manometers.

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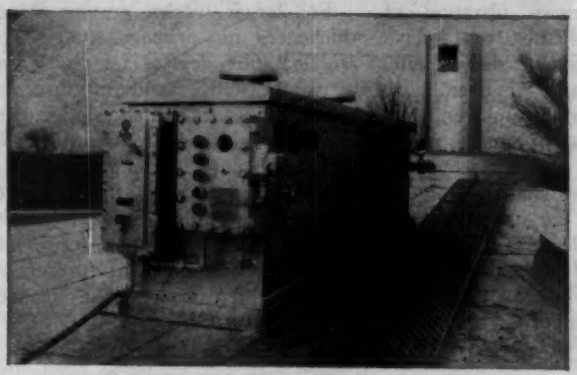
PFT-Kraus Nitrified Sludge —A process of aerating waste activated sludge, utilizing the digester supernatant liquor to produce highly nitrified solids that: (1) During *normal* loads, produce sludge that settles more readily to provide greater purification. (2) During *peak* loads, provide a reserve of highly nitrified active solids which balance the increased load of organic matter. A truly "controlled" activated sludge process.



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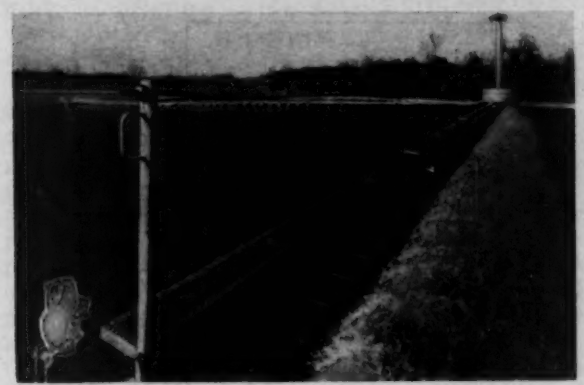

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sure by placing a floating cover in a separate sludge digestion tank. He also metered and used the process gas for heating the tank by means of a hot water heating coil, and he subsequently used the gas in engines.

By 1932, design development and promotion of the use of both floating covers and gas safety equipment established an important milestone in process efficiency—under conditions of safety. By 1946, the importance of close temperature control and its attainment, through the use of external sludge heating, had become generally recognized.

Despite these advances in the art, no substantial allowances in digester capacity were permitted by the several governing regulatory bodies; possibly because digesters have always been used, in large measure, as storage tanks. Digesters are still called upon to act as holding tanks for both the sludge-liquor and the bottom-solids which are awaiting further disposition. Thus exists the need for both digestion capacity and storage volume in a single vessel.

Computing Digester Size

As has been pointed out by Schlenz[1], in computing digester capacity, the volume requirements for digestion, sludge storage and supernatant should be computed separately. After determining volume requirements for digestion, additional cubage as may be required for sludge storage should be added to obtain digester size. If final sludge disposal includes the vacuum filtration of digested sludge, then 10 to 12 days storage might be considered adequate. On the other hand, if open sand drying beds are to be employed, then storage for 120 days, or more, might be required.

Storage for supernatant liquor can be minimized by the intelligent use of supernatant selectors and an appropriate type of discharge gauge.

Reducing the volume of the raw feed is also an important means of reducing digester volume. Use of devices of the type represented by the AccuRay unit of the Industrial Nucleonics Corporation, or a radioactive density meter for larger works, may very well develop into useful tools.

Use of a raw-sludge concentration tank, adequately equipped for liquor draw-off—and possibly having a simple aeration system for mixing the residuum, prior to transfer of sludge to a digester—could be a boon to small plants.

For larger works, gravity sludge thickeners for primary sludge, and air floatation devices for thickening activated sludge and mixtures of primary and activated sludge, are highly practical solutions to the problem of reducing digester volume.

Having winnowed the chaff of sludge and liquor storage from the kernel of solids-reduction, let us explore the possibilities of further increasing the capacity of a digester to do useful work.

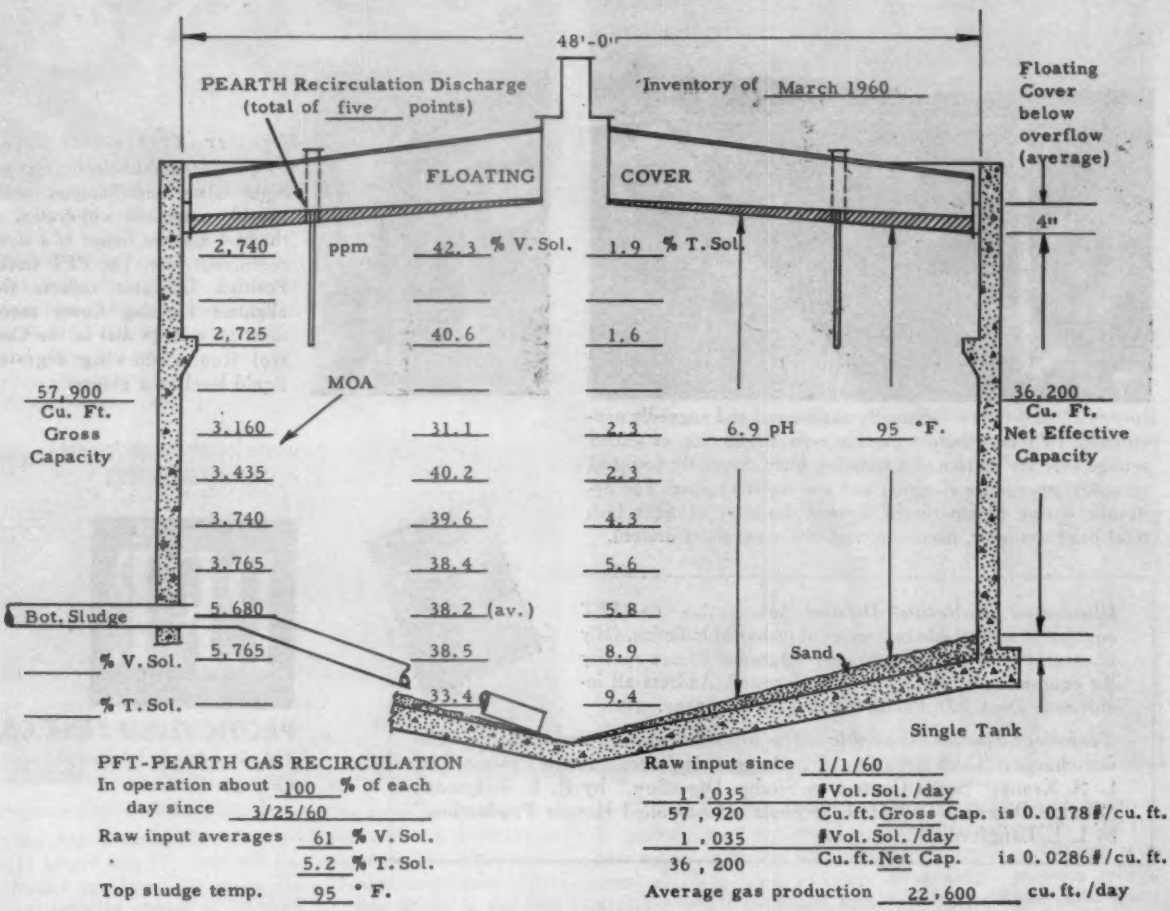
48'-0"
PEARTH Recirculation Discharge
(total of five points)
Inventory of March 1960
Floating Cover below overflow (average)
FLOATING COVER
4"
2,740 ppm 42.3 % V. Sol. 1.9 % T. Sol.
2,725 40.6 1.6
MOA
57,900 Cu. Ft. Gross Capacity
36,200 Cu. Ft. Net Effective Capacity
3,160 31.1 2.3 6.9 pH 95 °F.
3,435 40.2 2.3
3,740 39.6 4.3
3,765 38.4 5.6
Bot. Sludge
5,680 38.2 (av.) 5.8
% V. Sol.
5,765 38.5 8.9
Sand
% T. Sol.
33.4 9.4
Single Tank
PFT-PEARTH GAS RECIRCULATION
In operation about 100 % of each day since 3/25/60
Raw input averages 61 % V. Sol.
5.2 % T. Sol.
Top sludge temp. 95 ° F.
Raw input since 1/1/60
1,035 #Vol. Sol. /day
57,920 Cu. ft. Gross Cap. is 0.0178#/cu. ft.
1,035 #Vol. Sol. /day
36,200 Cu. ft. Net Cap. is 0.0286#/cu. ft.
Average gas production 22,600 cu. ft. /day

FIG. 1. INVENTORY of digester contents at the Somerset-Raritan, N. J., Joint Plant depicting solids classification.

TABLE I.
Summary of Operating Results From Digesters Equipped With P.F.T.-Pearth Multipoint Gas Recirculation

Location	1. Number & Diameter Prim. Dig.	2. Year Initial Opera'n	3. Loading # Vol. per Cu. Ft./day	4. Average of Digester Contents Tot. Sol.	5. Vol. Sol.	6. Average of Bottom-Solids Tot. Sol.	7. Vol. Sol.	8. Reduction Vol. Sol.
1. Darien, Conn.	1-30'	1957	.0756	4.10%	51.7%	6.40%	45.7%	59%
2. Oxford, Pa.	1-30'	1957	.0807	4.18	65.3	5.70	54.0	73
3. Arlington Co., Va.	1-65'	1957	.2440	5.00	60.0	6.00	55.0	75
4. Wilmington, Del.	1-90'	1958	.1140	4.22	41.2	4.80	37.3	61
5. Hartford, Conn.	3-51'*	1958	.1750	4.46	58.0	6.30	46.1	63
6. State College, Pa.	1-50'	1959	.1540	3.63	63.4	3.90	54.2	72
7. Somerville, N. J.	1-48'	1959	.0200	4.43	39.9	8.30	37.8	63
8. Lehighton, Pa.	1-35'	1959	.0540	4.50	53.0	6.26	53.2	72
9. Upper Moreland-Hatboro, Pa.	1-50'	1959	.0652	3.36	49.7	4.31	48.6	44
AVERAGES	50'		.1092	4.21%	53.6%	5.77%	47.9%	67%

Plants:—1. Sludge is regularly drawn from Primary Digester directly to drying beds, quite satisfactorily.
2, 7, and 8 represent Single Digester installations.
9. Activated Sludge Plant . . . . with the Pearth System is able to obtain 4.31% Bottom-Solids for withdrawal. Supernatant liquor from secondary digester averages .20% solids.
* designates fixed roof tank.
BOTTOM-SOLIDS CLASSIFICATION is clearly indicated by a comparison of Columns Nos. 4 & 6, and Nos. 5 & 7.

Efficient Use of Capacity

Supplementing the previous observation with regard to the theoretical requirements of sludge digestion, it might be emphasized that it is necessary for the active portion of a digester to unite promiscuously into one mass or to become incorporated indiscriminately together, to quote uncommon definitions of the term "to become mixed."

Heretofore, mixing has been of a limited nature, resulting from recirculating by pumping through process piping or otherwise, or from such mixing as the rising gas particles might impart to the mass. Present practice, confined to the principal proprietary methods includes, among others, use of mechanical mixing by means of draft tubes, having ports located just above the bottom of the tank and operated by propeller action. Used in conjunction with sludge thickeners, continuous or incremental feeding of raw sludge of 5 to 12% solids are introduced into a tank, wherein the mixers are reported to be sized so as to pump the equivalent of the tank volume in approximately 40 minutes. Complete homogeneity of tank contents is reported to be the objective.

Another example of propeller mixing is represented by an unconfined flat-bladed turbine, consisting of straight vertical blades mounted on a straight circular plate, driven by a vertical shaft. This circular plate, passing through the blades and shaft, divides the circulator into two units. It is reported that the shorter blades in the upper part set up movement along the roof of the digester to prevent scum formation. Also, the lower portion imparts an upward spiral velocity to the tank contents at the center, with a corresponding downward current at the tank wall. Velocities equal to at least ½ foot per second are reported to be maintained in all parts of the digester, even along the bottom.

Present practice also includes the use of recirculated compressed sludge gas for tank mixing.

One of these methods is using volumes of gas of about 1 cfm per foot of tank diameter, through diffusers placed at the bottom-center of the tank. They are designed to diffuse over an area equal to approximately 1/100 of the tank surface area, thus creating an unconfined gas lift, which, it is claimed, will produce true homogeneity within the entire tank contents.

A second design of this general type is described as a circulator-mixer, employing the airlift principle. Gas, compressed to 6 or 7 psig, is released in the center of the digester through one, or as many as six, stainless steel, gas discharge pipes, at a point approximately 10 feet below the surface. The compressed gas is released within a tube, which extends into the lower third of the digester terminating at its upper end in a distribution head box, which is submerged about 2 feet. Sludge is pulled from the lower zone through the lift tube and, by such action, creating a roll of the entire tank contents, which, it is claimed, provides a digester turnover every 45 minutes. It is further reported that this time is reduced on high-rate digestion. Again, a homogenized digester mass is the objective.

The singular objective of both the mechanical and gas-lift methods, briefly described, is true homogeneity of the tank contents and/or high bottom velocities.

Another method, also employing gas recirculation, has as its objectives the classification of the bottom-solids, together with complete mixing of the "digesting" portion of a digester.

Classification of Sludge Solids

Pearth Gas Recirculation allows for violent agitation throughout the entire tank depth, when required. This was the requirement at Petersburg, Virginia, where an iron oxide waste caused a bottom-sludge build-up of as high as 30 per cent total solids. After the installation of gas recirculation, bottom-solids have averaged 7.6 per cent total solids.

When digesting a more typical municipal sludge, the use of multiple, automatically and sequentially operated 2 inch diameter plain end gas discharge pipes, terminating 10 to 12 ft below the sludge surface, prevents both reactional and thermal stratification. Classification, in terms of both volatile and total bottom-solids can be observed at all of the 130 Pearth equipped digester installations presently in operation, and as typified by a typical inventory of a single digester (Figure 1) at the Somerset—Raritan, N. J. Joint Plant.

Table 1 presents a summary of plant operational values which plainly illustrate the advantages to be obtained by so operating as to insure optimum bottom-solids classification.

Even in large tanks such as the 90 ft diameter primary digester at Wilmington, Delaware, monthly inventories always reveal bottom material having the lowest per cent of volatile and the highest per cent of total solids.

The facility of the solids classification method of digester operation derives from the fact that gas mixing need only be used for whatever period of time is currently required.

At Winchester, Virginia, for example, it is used in the primary digester during the canning season, once every three weeks; at other times, only once every six weeks. It is also used about four times a year in the secondary digester, from which an excellent quality liquor is drawn through the supernatant selector. Again, at Lehighton, Pennsylvania, in a single digester, Pearth is used for about 33% of the time; this allows for obtaining a very satisfactory material through the supernatant selector.

At the University Park, State College, Pennsylvania installation, loadings are variable, because of seasonal academic activities; however, at a loading figure of 140 pounds of volatile solids per 1,000 cubic feet per day, a volatile solids reduction of about 68% is reported by Gifford[2] He further reports that, as the result of the excellently classified bottom-solids, vacuum filtration of digested sludge has been reduced from every two weeks to every three weeks, since the installation of the PFT-Pearth Process, in August, 1959. The same advantage has been indicated by Ford[3] at the Hatboro-Upper Moreland, Pennsylvania, activated sludge plant.

Summary

From the evidence considered, it would appear that digester volume requirements can be more accurately determined than heretofore. Also, that they can be reduced, to the extent that consideration is given to practical control of digester heating; raw-feed concentration; controlled supernatant removal and a flexible method of mixing which will allow for bottom-solids classification. When the latter is obtained, it will be found that the detention period of such bottom-solids is equal to or greater than the displacement period of the tank. This may well account for the excellent record of solids reduction which is reported from plants operated in this manner.

A recent study by Estrada[4], involving a comparison of the different methods of mixing in digesters provides additional information on the design criteria and factors affecting digester volume requirements.

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2. Gifford, David R., Chief Utilities Engineer, Dept. of Maintenance & Utilities, The Pennsylvania State University, University Park, Pa., in private communication.
3. Ford, Chester, Supt., Hatboro-Upper Moreland Sewage Treatment Plant, in private communication.
4. Estrada, Alfred A., Vice President, Albright & Friel, Inc., C. E., Philadelphia, Pa., "Design & Cost Considerations in the Use of High Rate Sludge Digestion", *Journal San Eng. Div.* ASCE, 86:SA3:111 (May, 1960).

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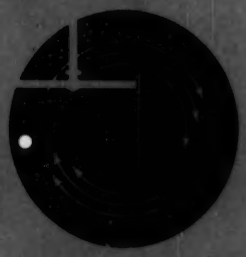

DORR-OLIVER EQUIPMENT AND SYSTEMS for the

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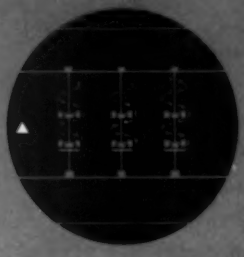

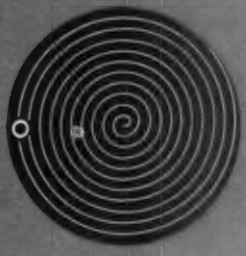

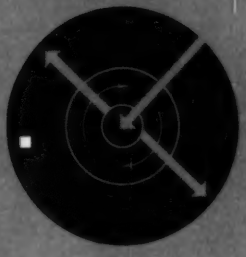

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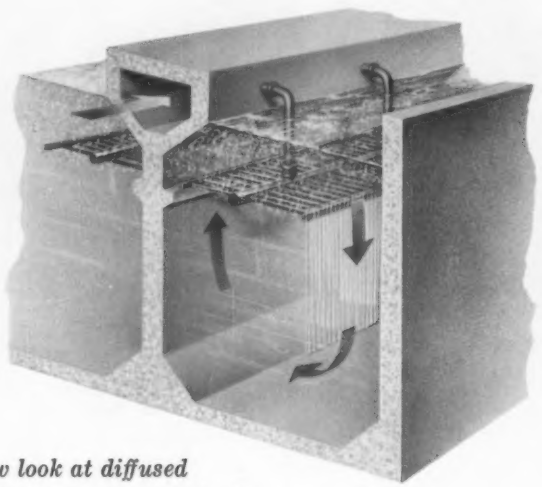

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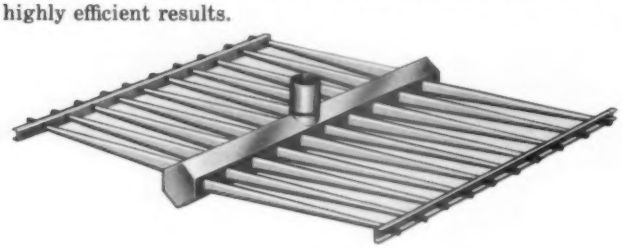

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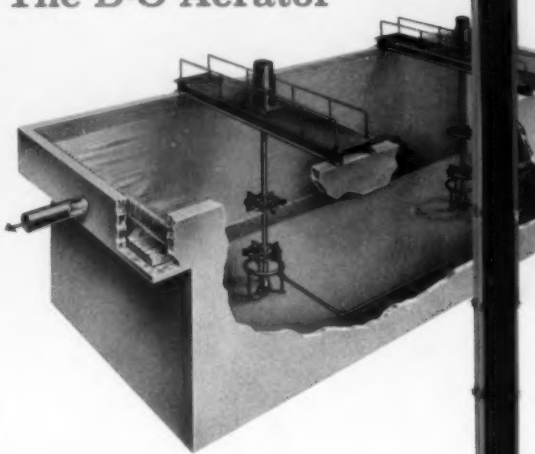

TURBINE AERATION Engineers are often presented with process problems requiring high oxygen transfer rates. The D-O Aerator can meet these requirements effectively and efficiently. The higher aeration capacity made possible by this unit allows a wide application to meet increased oxygen demands of concentrated activated sludges found in newer, short period, processes being adapted by municipal and industry plants.

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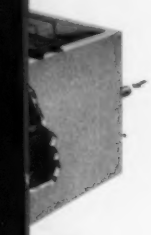

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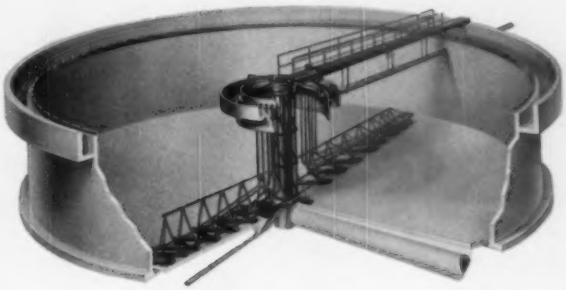

RAPID SLUDGE REMOVAL Here is the solution to the problem of excessive sludge detention in final clarifiers. Specifically designed for the rapid removal of solids on a continuous basis from secondary clarifiers, the RSR Clarifier is designed to:

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3. By rapid removal of sludge, promote better clarification, a fresher, less oxygen demanding return sludge and an effluent of higher dissolved oxygen content.

The RSR Clarifier is designed to carry out these key functions while at the same time incorporate certain distinguishing features not found in *any* other unit currently available. *Sludge removed from the floor of the tank can be readily observed, and its rate of removal can be controlled by an accessible, simple adjustment, see detail below.*

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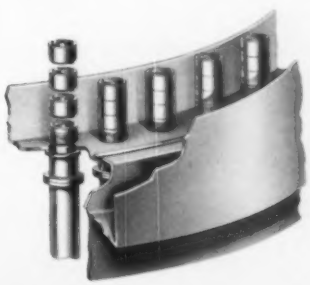
The RSR Clarifier, when coupled with an effective aeration system produces a highly efficient process team for activated sludge plant operation.



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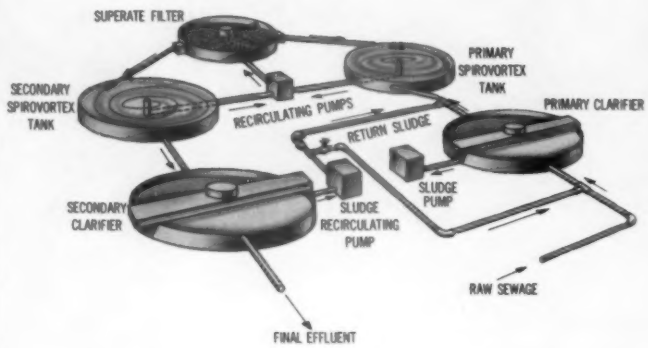
Activated sludge process

The Spirovortex System



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Fundamentals of Sludge Digestion

Part I

Biochemical Background

by GERSON CHANIN
Chief Sanitary Chemist
East Bay Municipal Utility District
Oakland, Calif.

RESUME: In part I, the author discusses the biochemical activities within a digester. In part II, the biological activity is described with particular attention given to explaining how it is affected by the environment in the digester. On the basis of this background of both the biochemistry and biology of the process, a discussion of what happens in a digester and its operation is developed.

■ SINCE ENZYMES ARE produced only by living cells, it is necessary to learn something about the living organisms involved in sludge digestion.

Although many different kinds of organisms, both plants and animals, are involved in sludge digestion, the bacteria seem to be of the greatest importance. Though bacteria will be described mainly, it should be remembered that many forms of life are involved, since all living cells produce enzymes.

Bacteria are extremely tiny forms of plant life. They are so small that they can be observed only by using a high-power, light microscope. Everyone has heard the word, bacteria, yet few recognize the full importance of these organisms. It is difficult to conceive how a group of living plants, so small that it might take 50,000 of them laid side by side to measure one inch and 40 trillion of them to weigh one gram could be of much consequence. Yet, in their absence, life as we know it could not be possible.

Suppose that man was capable of living, or at least surviving, at temperatures from freezing to boiling; suppose he could live either in the presence or absence of air, and under pressures of less than atmospheric to thousands of pounds per square inch; and further suppose that he was transparent or invisible. If all this was true, man would survive for a much longer time in this world than he does and his numbers would be vastly greater than they are. Survival of any particular species of life depends not upon its size, shape, physical powers, and such factors but mainly upon its ability to live and reproduce under a variety of environmental conditions. Since bacteria can live in almost any environment, they are universally present. It is because of their great adaptability to changes in environment that bacteria have been able to make their great imprint upon civilization.

In appearance the bacteria are quite different from other forms of life. When viewed under the highest magnification of the microscope, they are seen as tiny, transparent, generally colorless blobs of protoplasm; some spherical in shape, others cylindrical, and some shaped like a spiral or corkscrew. They may occur as individuals, as pairs, in chains, in clusters, or in other patterns. They exhibit no readily visible structures; no face, no body features, no limbs, no flower, no stem, no roots; nor any of the structures ordinarily associated with life.

Though unimpressive in appearance, they are of vast importance to life as we experience it. Were it not for the bacteria which bring about the rotting and decay of dead organic tissue, our civilization would shortly be buried in its own debris and waste products. Bacteria also play a major role in the return of nitrogen to the soil in a readily usable usable form, an essential step in the process of food production. Complete sewage purification depends upon the action of bacteria. Sludge digestion would probably be impossible in their absence.

In a manner analagous to that of all other forms of life, the health and activity of bacteria will be affected by changes in the environment such as sudden changes in temperature, the presence of same toxic or dangerous material, too much food, the wrong kind of food, too little food, the absence of air, etc. Bacteria, too, are subject to destruction by other forms of life.

Through similar to other forms of life, bacteria are quite unique in that all of the complicated biochemical processes ascribed to life are going on within one single cell. Yet, within this single bacteria cell, all of these complex physiological functions are carried on very efficiently.

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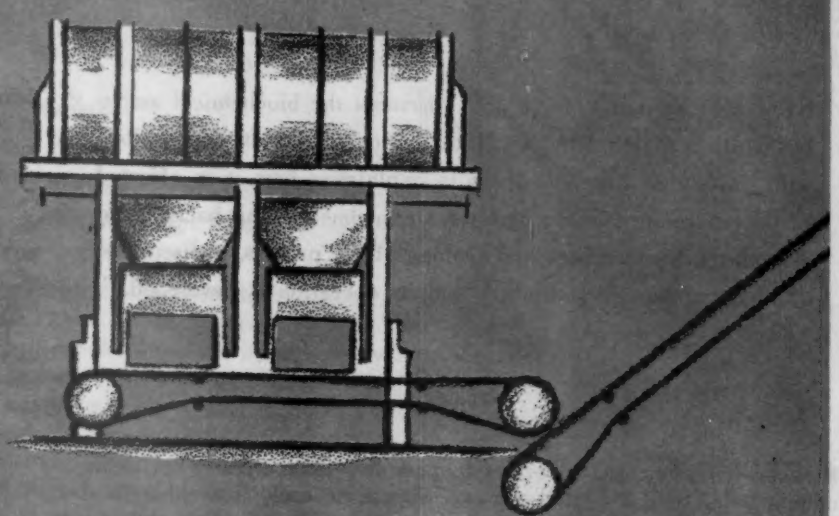

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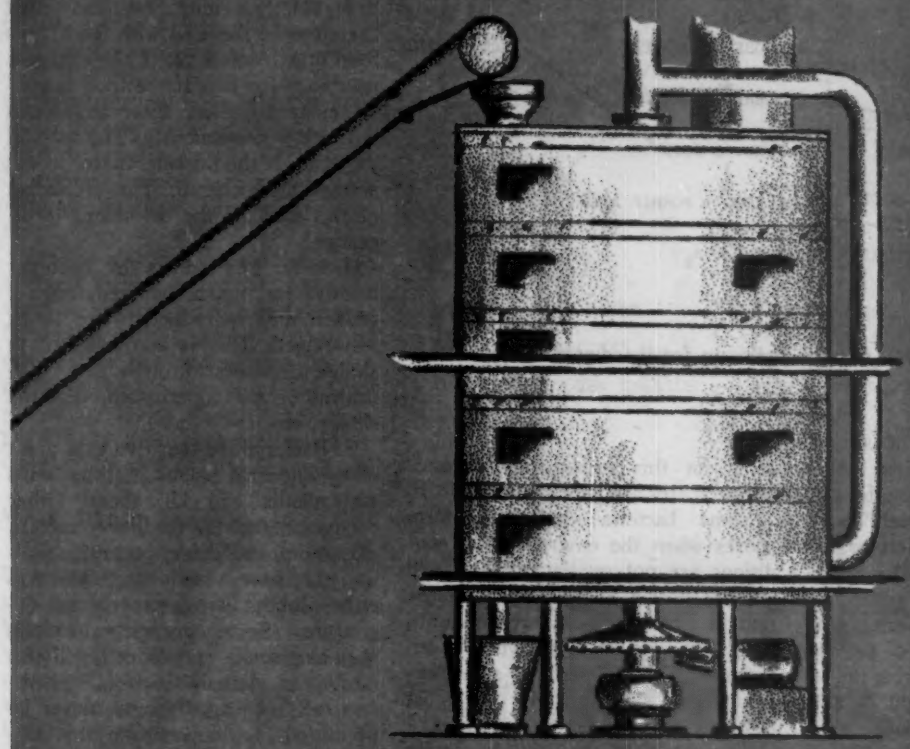

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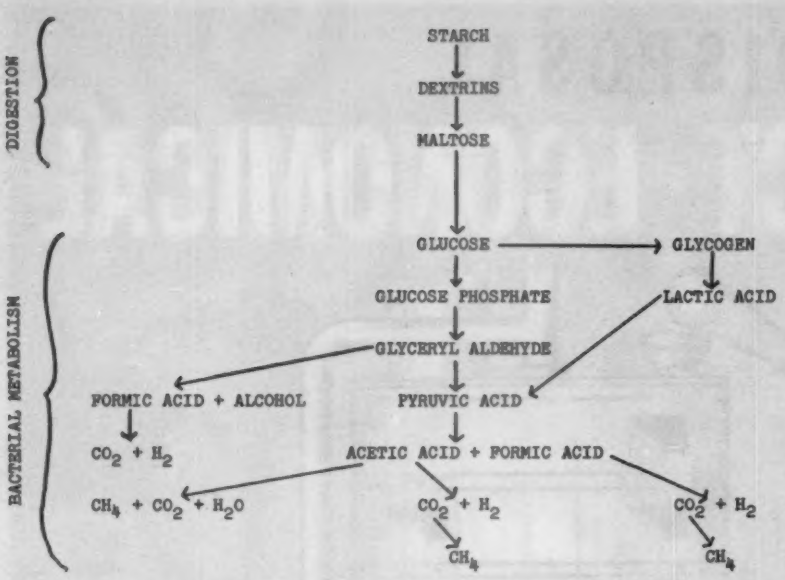

FIG. 1 ONE OF THE MANY possible pathways for the digestion and metabolism of starch

Bacteria also differ from other forms of life in the vast numbers of species and varieties which exist. Though all these tiny micro-organisms may appear to be alike in appearance, they may differ greatly in their physiology. One species may thrive only in the absence of air, another must have free oxygen for its existence; one species might be able to live on a variety of foods, while another may have a very rigid and limited food requirement; one species might thrive at a very low temperature, while another may thrive only at elevated temperatures.

No one knows how many species of bacteria are concerned with sludge digestion. Probably all of the organisms present are involved in the overall reaction in one way or another. In fact, the bacterial species present in one digester may be quite different from those in another. One thing is certain; a great variety and number of organisms, most of which have not even been identified, are present.

Despite the common belief, only relatively small number of bacteria are disease-producing; by far the greatest number of bacteria are harmless organisms, and in fact, the largest number are most useful to us.

Many bacteria like to grow at temperatures just slightly above the average temperatures in California; that is, from about 70° to 100° F. It is for this reason that digester temperatures are kept close to 95° F.

Some bacteria can even form spores when the environmental conditions are not satisfactory and will go into a sort of suspended animation in which they will remain until once again placed in a favorable environment. This permits some organisms to survive under the most rigorous environmental condition.

To reproduce, the bacteria merely split in two, forming two new individuals. The generation time is very short. A fifteen minute generation time is not unusual. It is entirely possible for one single organism to multiply to millions in twenty-four hours when placed in a suitable environment.

Having discussed very briefly the manner in which bacteria behave, let us examine the environment necessary for optimum bacterial growth.

1. While some bacteria can grow or survive over a wide range of temperatures, others will grow well only within a restricted range of temperatures. The bacterial types concerned with sludge digestion are the mesophilic bacteria; those which grow best at ordinary temperatures, somewhere between 68° F. to 112° F. Generally speaking, as the temperatures increase the rate of bacterial growth also increases, providing the temperatures remain within the normal temperature range for the organisms involved.

2. While a few bacteria can grow under acid or alkaline conditions the largest number of these organisms grow best at or near neutrality. The optimum range is generally given as pH 6.8—7.2, though many of these organisms can grow well at ranges from pH 6—8.

3. Bacteria must eat and must therefore be supplied with food. This food must contain all of the elements necessary for life. If the food is continuously supplied, these organisms will use it continuously. The food in digestors is the organic matter in the sewage sludge itself. The utilization of this food by the organisms is digestion.

4. The by-products of bacterial metabolism must be removed if growth and reproduction are to be maintained. This is accomplished in sludge digesters through the withdrawal of gas supernatant, digested sludge, etc.

5. Bacteria are sensitive to a great many chemical agents. Strong acids and alkalis will kill them. Other chemicals, such as the heavy metals, chromium, lead, zinc, copper, cadmium, etc., have a toxic effect and will either inhibit or destroy these organisms. Some organic chemicals such as phenols, cresols, etc., will also inhibit or destroy bacteria. Therefore, all such agents must never be permitted to concentrate to any marked degree in the environment.

6. Living organisms will grow and act best in a well-buffered environment. A "buffered" environment is one which contains within it various mechanisms to control the pH of the system even though additional acid or alkali is added to it. A great many such buffer systems are present in the digester. One such system, the carbonates, may be illustrated as follows:

This buffer system consists of the weak acid, carbonic acid, which results from the dissolving of carbon dioxide (CO_2) in water, and sodium carbonate, Na_2CO_3, which in water hydrolyzes as follows:

$$Na_2CO_3 + HOH \rightarrow NaOH + H_2CO_3$$

NaOH is a strong base and will neutralize excess acid introduced into the system. The carbonic acid formed by dissolving of CO_2 and that formed by hydrolysis, although a weak acid, will neutralize excess alkali fed into the digester.

Even the protein present acts as a buffer system since the many active acid and alkaline groups which it contains can act to neutralize added alkalinity or acidity.

These and other buffer systems are present in relatively large proportions in digested sludges. In this way the recirculation of digested sludge which contains buffering materials, aids in pH regulation.

It can be seen from what has been said that the environmental influences detrimental to bacterial growth are similar to those which adversely affect enzymatic activity. This is to be expected since both are protein in nature and since enzymes are produced by living cells.

It follows that, if digesters are operated in such a manner as to provide an optimum pH and temperature, and sludge feeds and withdrawals are balanced so that the organisms are neither overfed nor starved and also so that the waste products of metabolism are removed, then good digestion will be obtained.

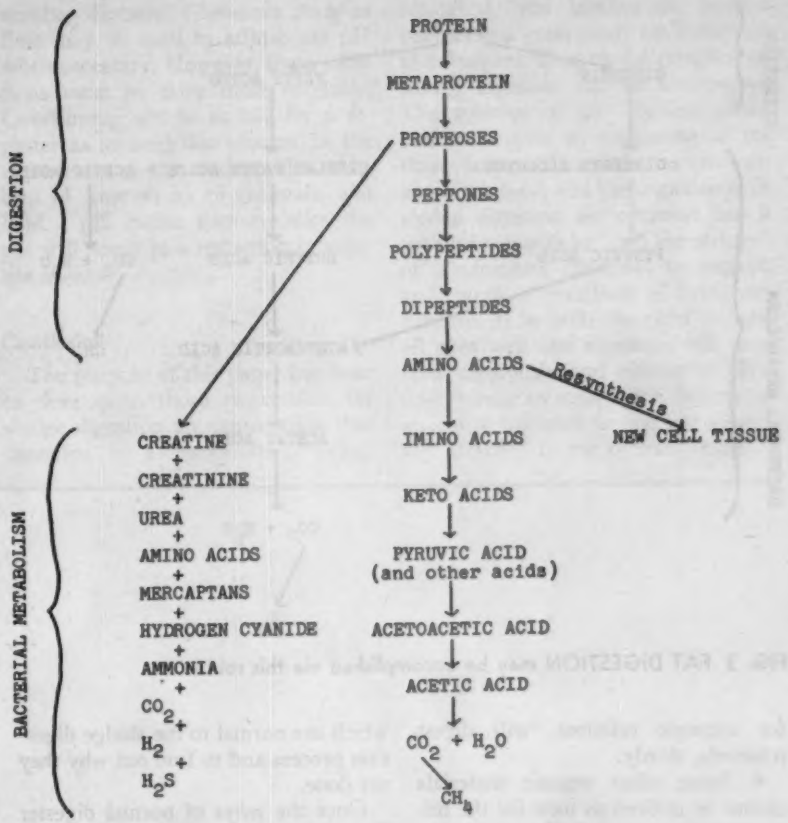

FIG. 2 A POSSIBLE PATHWAY for protein metabolism

What Happens During Digestion

The course of digestion should be almost evident from what has already been covered. Digestion has been described many times as a never-ending game between two teams, A and B. Team A's goal is to initiate digestion by converting the more complex organics in the sludge into simpler organic compounds. Team B's goal is to take these simpler organic compounds and convert them into gas, liquid, and ash. As long as both teams are up to full strength, and operating effectively, the game continues without end. Should either of these teams lose some of its players or some of its vigor, or should the weather (environment) be very bad, then the game soon ends and digestion ceases.

This game may be pictured as follows:

1. If the two teams are well balanced:

Team A		Team B
Complex organics ---------- →		Volatile acids ----→ CH_4, CO_2, H_2O

2. If Team A is weakened, there is no food produced for Team B and digestion ceases:

Team A		Team B
Complex organics ---------- →		

3. If Team B s weakened, the volatile acids are not converted into gas, and digestion ceases:

Team A		Team B
Complex organics ---------- →		----→
		Volatile acids ----→

Though this picture is both handy and readily understandable, like all other generalizations, it does not actually describe what is going on. The actual process is quite complex and not entirely understood.

It may be briefly described as follows:

1. Present in the tank are the organisms, food for the organisms, and an environment. In such a conducive environment, organisms will consume food for the purpose of reproducing the species. The types of organisms which will develop, and the results which will be obtained by way of the metabolic processes of these organisms, will be determined by the environment.

2. If the digester environment is maintained at an optimum; that is, at a near neutral pH, at a temperature near 95° F, and with controlled loading, then a variety of biochemical processes will follow, leading to sludge stabilization. Hydrolytic, extra-cellular enzymes which are present will attack the starches, proteins, and lipids (fatty material) and will eventually convert them into simpler organic molecules, including the so-called "volatile acids". These simpler substances are then utilized as foods by other bacteria and are converted by intracellular enzymes into even simpler chemical substances such as, CO_2, CH_4, and water. Both of these processes are going on simultaneously in any operating digester so that the individual steps cannot readily be observed. The overall reaction can be evaluated by following such things as the gas production and the volatile solids reduction. An indication of how both systems, A & B, are faring together can be obtained by measuring such things as the volatile acids, the pH, the alkalinity, the composition of the gas, or the oxidation-reduction potential.

3. Some materials in the sludge,

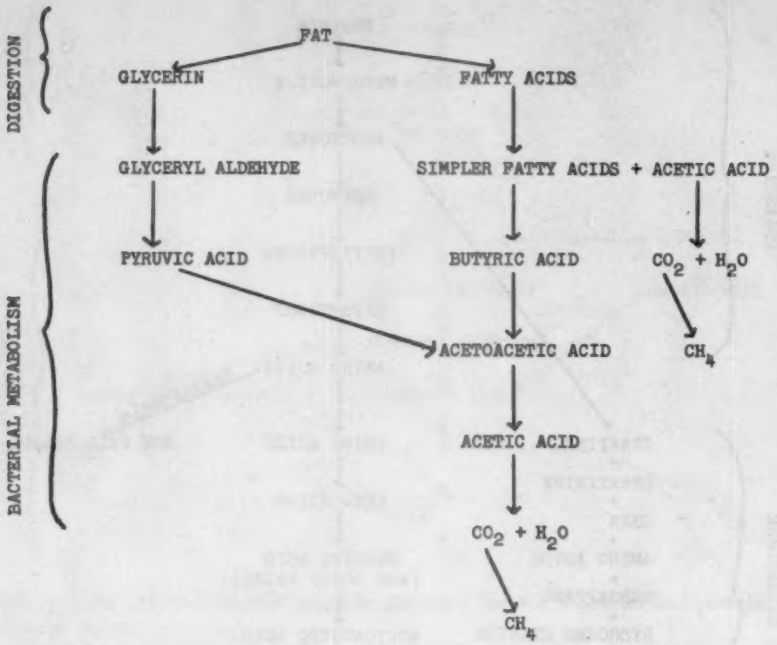

FIG. 3 FAT DIGESTION may be accomplished via this route

for example cellulose, will digest relatively slowly.

4. Some other organic materials cannot be utilized as food for the micro-organisms and will not be digested at all.

5. Also present are scavenger organisms, generally microscopic animals, which eat the bacteria and keep their numbers to an optimum level. If the bacteria were allowed to build up to huge numbers, there would not be enough food for all of them and they would begin to die. This could eventually result in a cessation of digestion. Careful control of feeds and draw-offs also aids in this population control.

Even this explanation of what goes on in digestion is a great oversimplification but it will aid in the understanding of the *whys* of digester operation.

Understanding Digester Operation

Essential to an understanding of digester operation is an appreciation of facts already mentioned; namely, that digestion is a biochemical phenomenon involving organisms, enzymes, food, and environment. Wise operation depends upon doing those things which can be done to enhance this phenomenon.

With this background, understanding can be best obtained by re-examining the operational procedures which are normal to the sludge digestion process and to find out why they are done.

Once the *whys* of normal digester operation are clearly understood, a decision as to what changes to make when something goes wrong with digestion can be arrived at in a relatively simple and logical manner.

Seeding Since the primary reactions are biological, it would greatly help if we could seed the raw incoming sludge with the organisms required for its digestion. One way this is accomplished is to allow the fresh sludge to enter near, but above the center of the tank, so that it will have to fall through an actively digesting layer and become seeded. Many different recirculation schemes have been employed for just this purpose. Introducing raw sludge into the recirculating sludge will result in good seeding. In a new digester seeding is accomplished by the addition of well-digesting sludge from some other treatment plant to provide both a supply of organisms and buffer materials.

Supernating To make room for the addition of more raw sludge to a tank it is necessary to withdraw some materials from the tank. Supernating, however, does more than just this, since in this supernatant certain undesirable or excessive amounts of metabolites and excess organisms are removed from the system. This is one of the many ways in which a favorable environment is maintained.

Feeding A digester must, of course, be fed so that food is provided for all of the organisms involved. This food should be added in such a manner that the organisms will continuously work at their optimum rate. Technically this is known as, "keeping the organisms in their logarithmic growth phase." However, feeding must be so regulated that the system is not overfed; this would cause a buildup in organic acid production because of the breakdown of solids in the sludge to the point where the acidity would inhibit or destroy the hard-working organisms. On the other hand, underfeeding or starving will also result in inhibition of these biochemical systems or in death of the organisms.

Feeding, supernating, and sludge draw-offs must be considered together and balanced so as to provide optimum conditions. Towards this end it is generally recommended that the raw sludge solids being added daily to a tank equal about 4 per cent of the dry solids in the digester.

Mixing Since biochemical reactions are involved, it is necessary to bring the reactants together before a reaction can follow. The more intimate and the more frequent this contact, the faster will be the speed of the reaction. These reactions involve bringing the organic chemicals in contact with enzymes and/or organisms. Many mixing schemes are employed, such as seeding, mechanical stirring, liquid recirculation and gas recirculation; and though they may appear to be different, their goals are the same.

Heating Since biochemical reactions within certain limits will proceed faster as the temperature is increased, warming the digester contents to temperatures around 90-100° F will also increase the rate of reaction.

Sludge Draw-off This has already been considered to some extent. The draw-off of digested sludge must be accomplished in such a manner as not to deplete the food supply or the buffer capacity of the system. Well digested sludge is a good source of both organisms and buffer for seeding purposes. Sufficient digested sludge should always be kept in the digester to meet its normal organism and buffer demands, to allow correction of unusual conditions, or to pre-

vent changes in the environment. Mild acid disturbances brought about by transitory overloadings can be readily corrected by the recirculation of more than the usual amount of digested solids.

pH Control Adjustment of the pH of a digester is not a simple matter. The most obvious method of control is the regulation of raw sludge feed. Since organic acids are produced in the early stages of digestion, cutting down the sludge feed will cut down the amount of acid production, and thus serve to adjust the pH. However, this can be done only where it is possible to bypass the sludge to another digester. Chemicals such as lime may be used to adjust the pH when necessary. However, these additions must be done most carefully. Over-liming can be as bad for a digester as an acid disturbance. In the experience of the author, the addition of lime so as to maintain and hold a pH rather than to raise the pH will result in a reduction in volatile acidity.

Conclusion

The purpose of this paper has been to develop in those responsible for sludge digestion an appreciation that digestion is a complicated, living, biological, and biochemical process subject to a great many environmental influences. Despite the complexity, sludge digestion can be understood. The solution of any digester problem rests upon an evaluation of the three factors discussed, the environment, the food, and the organisms. In sludge digestion the operator has it within his power to "pull the strings" of a miniature universe; to exploit, as it were, a multitude of living organisms. If he pulls the right strings, all goes well and digestion will proceed vigorously and efficiently. The opportunity to control the destiny of an entire universe is one not generally afforded to the ordinary man.

Fundamentals of Sludge Digestion

Part II

Biology and Operation

by GERSON CHANIN
Chief Sanitary Chemist
East Bay Municipal Utility District
Oakland, Calif.

RESUME: To complete the coverage of this subject, this concluding article discusses first the biology of an anaerobic digester, giving particular attention to the environment needed for active, effective digestion. Such items as temperature, pH, food supply, waste products and others are discussed in regard to their effect on the process. Then this information and that presented in Part I are used as a basis to discuss the process as it takes place in a digester. Among the subjects covered are seeding, supernating, feeding and heating.

■ IN THE SAME SENSE that the brewer does not actually "make" beer, or that the vintner does not actually "make" wine, or that the pharmaceutical chemist does not "produce" antibiotics, so too the sewage treatment plant operator does not really "treat" sewage. In reality sewage contains within it all of the elements necessary to "treat itself" and, as a matter of fact, sewage will treat itself whether or not it flows to a sewage treatment plant. The same may be said of sewage sludge digestion; it, too, contains within it the elements for its stabilizations; i.e., its decomposition.

A fundamental of biology is that in a given system consisting of a variety of organisms, plants and/or animals, a food which can be ingested and digested, and an environment in which the food can be utilized, a series of changes will occur which will result in a balanced ecological universe dedicated to the efficient utilization of energy from the food provided for the purpose of reproducing the various species involved. In other words, by this process called "living" a species tends to perpetuate its kind through the conversion of food materials into energy and the subsequent formation of new cell tissue.

The chemical substances which are involved in such ecological systems have been with us on this planet for a great many years. These same chemicals have been used and reused, changed and transformed, a vast number of times; but are, on the whole, from nature's original pool of chemicals, solids, liquids, and gases from which life first developed on this planet. Thus, all life is just part of a complex ever-continuing cycle of events.

Sewage treatment and sludge digestion and the industrial fermentations previously mentioned are examples of some of the innumerable systems which make up this complex cycle of life. Since sludge digestion is a living system, it can best be understood by way of the biological and biochemical explanations of what goes on in the system.

Stripped of its adornments, a digester is a miniature "universe" containing within it foods, carbon compounds, etc., and a myriad of organisms adapted to or trying to adapt themselves to a particular environment. As a result of this activity a balanced ecology will result. There will develop a variety of bacteria and other organisms to best ingest and utilize the different kinds of foods which may be present. There will develop a variety or organisms to control and regulate the system so that all the various forms of life will live and perform at the peak of their efficiency. There will develop a variety of scavenger organisms to utilize and dispose of the waste products, and of dying or dead organisms. These organisms and others will develop and form a well-balanced biological universe dedicated to the utilization of energy from the sewage sludge. This is sludge digestion.

From the standpoint of the sewage treatment plant operator, sludge is that black, smelly, difficult-to-handle conglomeration which he must tranfer from the sedimentation basins to the digesters in order to accomplish several goals:

1. To reduce the volume of the sludge.
2. To reduce the amount of organic, volatile, solids in the sludge.
3. To render the sludge less obnoxious and more readily disposable.

The City of New Albany, Indiana, recently placed in operation a single plant which combines both mixed refuse and sewage sludge disposal functions. The installation of the C-E Incinerator Stoker and the C-E Raymond Flash Drying System at this same site enables New Albany to benefit from the economies inherent in a dual purpose plant.

Two C-E Incinerator Stokers with a daily capacity of 80 tons each, reduce refuse to a sterile ash that is free from clinkers and suitable for use as a sanitary land fill. "No-cost" Btu's from the burning refuse are used by the C-E Raymond Flash Drying System for drying the sludge. The utilization of this heat eliminates all auxiliary fuel requirements.

Primary sludge filter cake is reduced to approximately 8 per cent moisture content in the C-E Raymond Flash Drying System. The dried product can be sold for use as a soil conditioner to help defray plant operating expenses, with any excess being burned in the refuse incinerator.

Each of these C-E systems has been service-proved in installations large and small, and the combination furnishes a dependable and economical solution to a community's sewage-refuse disposal problems. Your nearest C-E office has more information readily available to you or your consultants.

New Albany operates combined mixed refuse and sewage sludge disposal facilities at same plant site

The Municipal Sewage Treatment and Incinerator Plant at the City of New Albany, Indiana, contains the C-E Raymond Flash Drying System and two C-E Incinerator Stokers.

Consulting Engineers:
Consoer, Townsend & Associates, Chicago.

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COMBUSTION ENGINEERING

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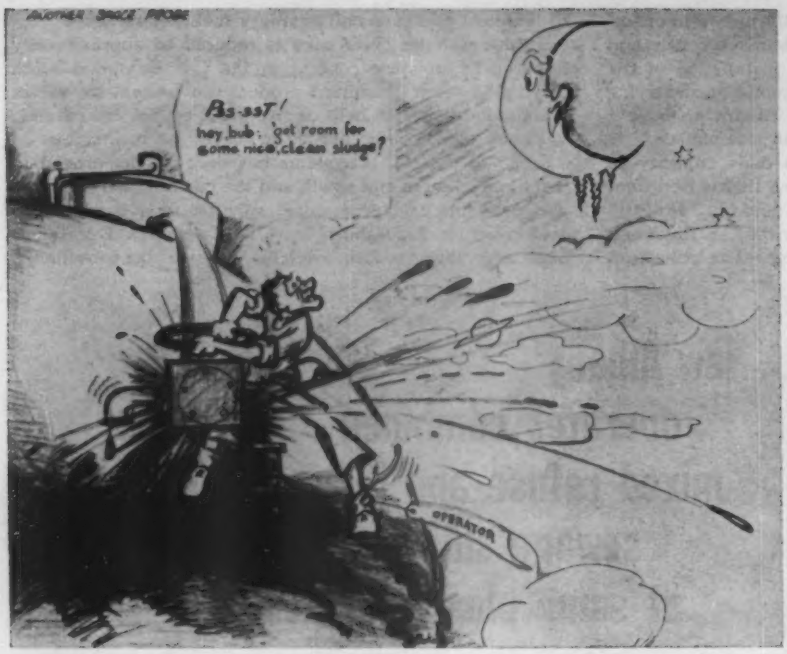

FIG. 4 A UNIVERSAL PROBLEM in sludge digester operation

4. To alter the physical state of the sludge so that the accompanying water can be readily removed.
5. To convert some of the organics into energy which he can collect and utilize.
6. All of this must be done economically and in a controllable manner.

From the biologist's or the biochemist's viewpoint, sludge is a very rich mixture consisting of a relatively large amount of organic matter, food; a large variety of organisms, both animal and vegetable; water; and miscellaneous artifacts. He recognizes that, if a suitable environment is provided, growth and reproduction and all its attending changes will occur. The problem of sludge digestion reduces to the questions: What are the desired end products and what environment will bring them about? This paper will study sludge digestion from the standpoint of the environment influences which lead to good digestion.

Biochemical Background

All sewage sludge contains within it the necessary constituents for its own decomposition. First, organic matter or food is present; this includes, starches, sugars, celluloses, proteins, fats and oils, amino acids, fatty acids, other organic acids, urea, and many others. Secondly, other necessary nutrients such as nitrogen, phosphorous, minerals, vitamins, etc., are present. Thirdly, a variety of organisms are present. While many of these organisms have not been identified and their properties are not entirely known, they are of a wide variety including many different species of bacteria, protozoa, yeasts, and molds, as well as some of the higher plant and animal forms.

It is known that the early stages in the decomposition of organic food, brought about by these organisms, proceeds along lines quite similar to those which occur in the early stages of human metabolism; hence the name "digestion" seems most appropriate. Technically, however, more than just digestion occurs in a sludge digester. In the human, digestion is the breakdown of complex foods, such as starches, poteins, and fats, into simpler compounds which are either soluble, or small enough to pass through the walls of the stomach and the intestines into the blood stream for further usage. This is where human digestion ends. The subsequent breakdown and conversion of these absorbed substances to yield even simpler compounds and energy is commonly called "burning the food" or "breaking-down process" or technically, *catabolism*. Some of the simple substances so produced recombine to form the complex chemical of cell tissue. This process is called the "building-up process" or *anabolism*. Actually, these processes go on simultaneously and the overall process is called *metabolism*. In sludge digestion both digestion and metabolism are going on.

The decomposition and utilization of carbohyrates, proteins, and fats in man is an extremely complicated process involving a great many steps; nevertheless, these steps are fairly well understood. For the purposes of this brief introduction to sludge digestion, it will suffice to outline schematically some of the reactions which could be going on in the bacterial decomposition of sludge solids. These are shown in Fig. 1, 2, and 3. Anaerobic and aerobic bacterial decomposition both begin in the same manner, but somewhat different end products are produced.

The active processes going on in digestion are probably far more complicated than those shown in these figures. Fig. 1, for example, illustrates only one of the possible pathways for the decomposition of only one of the carbohydrates. In the early stages of cellulose, another carbohydrate, the degradation would be quite different than those shown in the figure for starch. However, once the cellulose was broken down to the glucose stage, subsequent metabolism might be the same as in the case of starch. The end products of bacterial metabolism could be other than those shown and would depend upon the bacterial species involved and the environment.

The schemes presented in Figs. 2 and 3 are also only approximations of the actual processes which may be going on; these, too, will depend upon the species of organisms involved.

In all of the pathways indicated, the starting substances, the carbohydrates, fats, and proteins are very complex . large organic molecules which, as the process of decomposition continues, are successively broken down into simpler and more simple compounds to finally end up as very simple chemical substances. In these processes energy is liberated.

If you burn wood or paper in a fireplace, much heat (energy) is given off, as well as carbon dioxide and

Make a continuous, accurate record of filter cake weight with a...

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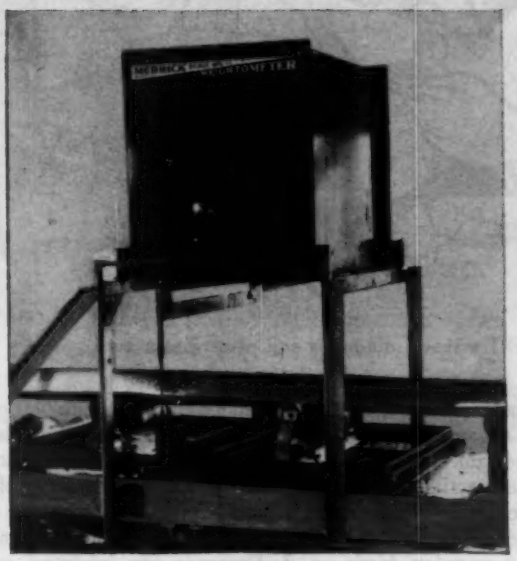
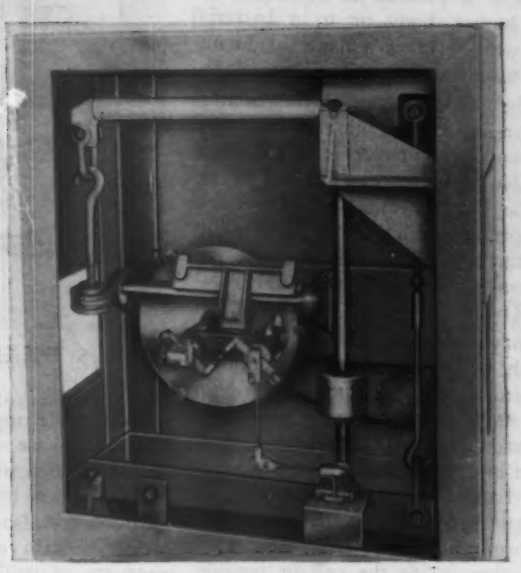


Type E Weightometer.



Type SV Weightometer.

Accurate totals of the solids are easy when a sewage treatment plant has a Merrick Weightometer. The Weightometer continuously records the total weight of filter cake or sludge carried on a moving conveyor by measuring and integrating the varying load on the conveyor with the fluctuating speed of the belt. Proved by fifty years' use in every type of bulk materials handling found in industry, the basic principle of the Weightometer has been refined until accuracies of better than 0.5% can be guaranteed.

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water; an ash remains. If wood or paper are decomposed according to the schemes shown, though the intermediate steps are quite different, though no fumes are evident, and though the reaction is slower, the same final end products are formed; and theoretically the same amount of energy is produced per unit weight of starting material decomposed. How is it possible to accomplish in the human body or in a bacterial cell what it takes a flame to do under usual conditions?

The secret to the phenomenon is the presence of organic catalysts called *enzymes*. A *catalyst* is a substance capable of increasing the rate of, or of starting a chemical reaction which is normally either slow or difficult to start; yet, at the same time, the catalyst is not used up in the catalyzed reaction.

Enzymes cannot initiate a reaction which is not possible chemically or physically; they can merely speed up or start a reaction. Chemically, enzymes are complex proteins capable of bringing about certain biochemical changes at normal temperatures and pressures. These enzymes, which are produced by all living cells, may act either inside the cell or outside the cell. They can be extracted from living tissue and will perform their activities even in a test tube. Yeast as purchased at the supermarket is exactly such a preparation. When added to bread dough, the enzymes in the yeast cause an alcoholic fermentation (decomposition) of some of the carbohydrate in the dough, during which gas production causes the dough to rise. Similar types of enzymatic reactions occur in a sludge digester, some taking place in the liquid itself and others taking place within the living cells present. Those enzymes which are produced in the cell and then discharged to the environment so that they act outside the cell are called *extracellular enzymes;* the others acting in the cell are called *intracellular enzymes*. Both types of enzymes are normally required. It should be remembered that, in all living tissues, decomposition and metabolism are accomplished through the activity of these biochemical catalysts. Since the extracellular enzymes are largely involved in metabolism, it may be said that in sludge digestion, digestion occurs in the liquid phase in the digester while metabolism occurs in the solid phase, the organisms which are suspended in the tank contents.

Mmmm --
Sludge too rich; gas too poor. Th' kid's got indigestion. Cut out those potent medicines; give 'im some rest; & let nature take it's course
Ol' Man
DUMP'N BURY
OP

FIG. 5 THE EXPERT makes a diagnosis and prescribes a cure

In addition to these activities, organisms are also present in digesters which contain enzymes having the property of utilizing complex foods and converting them rather directly to extremely simple gases like CO_2, CH_4 and acids like acetic, butyric, and lactic. This process is called *fermentation*. Several such fermentations do go on in sludge digestion.

Enzymes are proteins; therefore, anything which can affect or react with protein will also affect enzymatic reaction. Though quite a bit is known about proteins, their structure is so complex that they have not yet been completely characterized. Nevertheless, certain properties of proteins are well known.

1. Enzymes, like other proteins, are inactivated at temperatures above 70°-80° C (158-176° F). In general, however, the rate of enzymatic reaction is directly proportional to the temperature up to the point where inactivation occurs. Inactivation of some enzymes begins at temperatures as low as 50° C 112° F).
2. The catalytic effect of a particular enzyme is generally exercised over a rather restricted range of pH. This range is not the same for all enzymes, though a great number of the enzymes are most active between pH 6-8. This is analagous to the denaturation of protein which occurs in the presence of added acid or alkali.
3. Enzymes are inhibited or destroyed by a great many substances, particularly the so-called "toxic" substances. Any chemical which is protein denaturant will adversely affect enzymatic action.

It is well known that proteins are essential to life, yet the many important roles which proteins play are not fully appreciated by the ordinary man. It is by way of a protein reaction that immunization against disease can be obtained. A minor difference in the protein material of blood makes it possible to differentiate the bloods of different species and sometimes even that of individuals of the same species. A small variation in the proteins of the blood makes certain medical diagnoses possible. Allergic reactions involve a protein reaction or alteration. The very physical and chemical nature of the living cell itself depends to a large extent upon the properties of protein. These and many other vital functions are controlled by protein in one way or another. It is small wonder, then, that enzymes possess peculiar and extremely important characteristics.

FIG. 6 PROPERLY MANAGED, a sludge digester can "go to town"

The structure of proteins, and therefore also of enzymes, is such that the surface of the molecule is covered with a great many active chemical groups which may react with a wide variety of substances. Therefore, for optimum reactivity the protein and/or enzyme environment must be carefully controlled. This control will include:

1. Providing optimum temperature
2. Providing optimum pH
3. Exclusion of inhibiting agents
4. Exclusion of toxic substances

It has been estimated that about 60 per cent of the dry weight of the cell is enzymatically active protein of thousands of different kinds. Since these enzymes are not used up in the reactions they catalyze, a relatively large amount of enzyme activity would be expected in a biological system like a sludge digester. In the organism *Escherichia coli* alone, some 50 different enzymes have been identified.

It must be concluded that these enzymes are a most important factor in sludge digestion.

Information on a new development in England. The use of . . .

Sludge Gas Turbines

for Sewage Plant Heat and Power

from the BRITISH INFORMATION SERVICE
New York, N.Y.

RESUME: One of the largest treatment plants in the world will supply its own heat and power with turbines utilizing sludge gas as fuel. The air required for the activated sludge plant being put into service by the London (England) County Council wil be supplied by blowers powered directly by the turbines while the hot water needed for heating the digesters will come from heat exchangers on the turbine exhausts. The air for both the turbines and the blowers will be taken from a common trunk into which air is drawn through electrostatic filters. Sludge gas is compressed by a two cylinder; two stage compressor which is powered by a motor in another room. It will receive its power via a shaft sealed at the wall. Of the eight turbines installed five are prime movers for the blowers while three drive generators through reduction gears. These units provide 100,000 cfm of air and 1865 kw of electric power. Between 20,000,000 and 30,000,000 BTU's will be extracted from the turbine exhaust to maintain a temperature of 85 to 90° F in the digesters.

■ Eight gas turbines, running on sludge gas, are the source of all the power and heat needed by the new sewage plant, one of the largest in existence, which the London County Council is bringing into use at its Northern Outfall Works at Beckton, Essex, England.

These works, started in 1864, now serve 112 square miles of London and have a dry-weather flow of 178 mgd. The use of gas turbines, running on sludge gas, as the primary source of power distinguishes it from all other sewage works in the United Kingdom, if not in the world.

Power House Services

Two of the services provided by the power house are (a) a continous flow of air to the diffused air activated sludge plant and (b) a continuous supply of heat for the covered primary sludge digesters. The primary digestion tanks are also the source of the sludge gas, which is suspected to be 70 percent methane and 30 percent carbon dioxide, which the gas turbines will use as fuel.

To meet the air demands of the activated sludge aeration tanks the power house must supply 100,000 cfm. To drive the pumps, scrapers, penstocks, power house auxiliaries and other equipment associated with the plant it must generate 1,865 kilowatts of electrical power. The primary digestion tanks need between 20,000,000 and 30,000,000 BTU per hour, according to the season, to maintain a sludge temperature of 85 to 90°F. When the scheme is in full operation, the digestion tanks will yield approximately 2,700,000 cubic feet of sludge gas per day.

Turbine Details

The turbines are basically similar to the standard Ruston Type "TA" which are used by the petroleum and other industries for a wide variety of duties. Five are directly coupled to air blowers and three drive generators through a 41 reduction gear.

Each turbine has its own console and, when running, can be controlled from the console or from the control room, a glass-fronted structure from which the engineer in charge commands an uninterrupted view of the turbine hall.

Starting is by electric motor drawing current from batteries. Incoming air, compressed by a 13-stage axial flow compressor, passes through the heat exchanger, and thence into the combustion chamber, where it is mixed with fuel and burned. The gases of combustion pass through a two-stage power turbine, again through the heat exchanger by different channels, through the water heater and finally, by underground ducting, to the appropriate chimney.

All five air blowers are of the single-stage, double-entry centrifugal type directly coupled to the turbines, each with a rated output of 25,000 cfm at a pressure of 7.5 psi at 6,000 rpm. Pressures up to 8.5 psi can be reached by running the turbines at higher speeds.

Delivering Sludge Gas

Air for the blowers is cleaned by being passed through electrostatic filters in six of the filter chambers. So, too, is the 115,850 cfm of air needed by the gas turbines. Both blowers and turbines draw their supplies from a gallery, running the length of the power house, which the air enters on leaving the filter chambers.

These are rated at 750 kw, but will normally deliver 620 kw at a power factor of 0.8 at 3,300 volts at 1,500 rpm. Outputs up to 750 kw can be obtained if required by running the

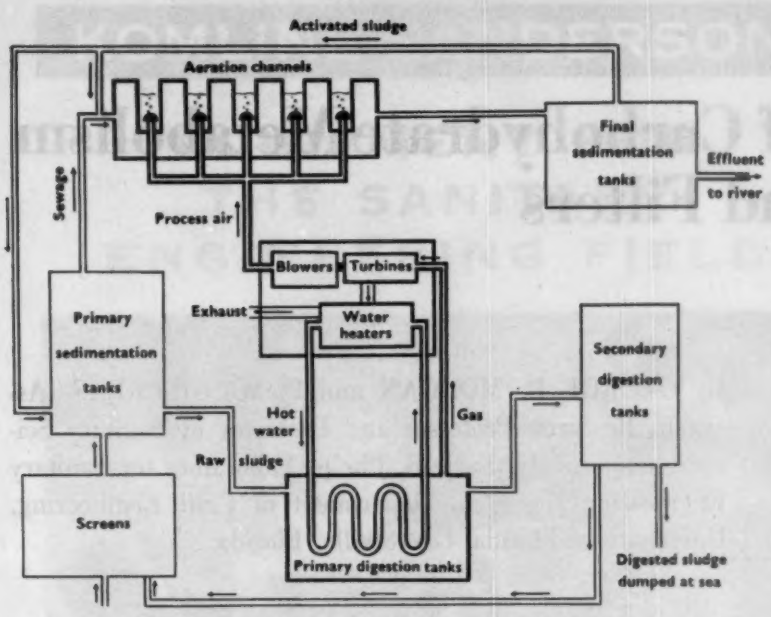


FIG 1 SCHEMATIC DIAGRAM of the Northern Outfall Works

turbines at higher blade temperatures.

Sludge gas is delivered from the digestion tanks to the power house, under slight pressure, by an 18 in. main. From the main it passes to two-cylinder two-stage, double-acting, inter-cooled compressors, each with a capacity of 750 cfm which, after increasing the pressure to 120 psi pass the gas to two receivers in the compartment each holding 1,050 cubic feet. The compressed gas reaches the turbines by way of a high pressure main in the basement. The compressors are housed in a separate compartment off the turbine hall, and are driven by 180 horse-power induction motors in the turbine hall by means of a V-belt reduction drive and sealed shaft through the wall. They come into operation, or are off-loaded, automatically as demand rises and falls.

Five compressors are installed, three of which can meet the normal demand for gas. One compressor is thus available for stand-by duty and the other for overhaul.

The Water Systems

The water heaters are designed to extract 3,100,000 BTU each per hour from the exhaust gases of the turbine, giving a total of 21,700,000 BTU per hour under normal conditions from seven working turbines. The water is heated to a temperature of 165°F. and is circulated through the heaters, 12 inches mains and sludge coils by one of two electrically-driven centrifugal pumps each with a capacity of 1,650 gpm. Some of the water is used for space heating and domestic purposes in the power house and for the heating coils in the main fuel oil storage tanks, built outside the power house, which supply oil to the service tanks in the oil store. The hot water system is pressurized by a large surge tank in the roof.

Cooling water for the turbine lubricating oil, gas compressors and other purposes is drawn from the cooling water pond and circulated by an electrically-driven centrifugal pump. The water is returned to the pond through cooling sprays.

All necessary instruments are fitted to give complete information on plant operating conditions. The principal instruments and controls are grouped in the control room, and include a main electrical panel for the remote operation of the 3,300-volts and 415-volts switchgear, generators and gas compressor motors. The control panel is complete with a schematic diagram which gives immediate indication of the switching arrangements and plant in service.

Precautionary Measures

Instruments associated with plant performance are all of the recording type so that efficiency of operation can be determined over any period.

In the planning of a sewage treatment plant as big and complex as that at Beckton the risk of plant failure must be virtually eliminated. In consultation with the London County Council therefore, Ruston and Hornsby Ltd., of Lincoln, England, considered every foreseeable combination of circumstances that might jeopardize the smooth and efficient flow of the treatment processes day and night, year after year, and took all practical measures against them. Most of the precautions were specially designed for this installation. For example, if the supply of sewage gas falls below demand, the gas turbines can run on liquid fuel. In the event of a complete electrical failure, one of two selected blower sets will automatically change from sewage gas to liquid fuel and draw current for its emergency fuel and forced lubrication pump from the starting batteries.

An alarm annunciator panel in the control room and visual and audible signals give warning of abnormal conditions in any of the services, for instance, too high a temperature in the hot water heaters, or too low a pressure in the gas receivers. By-passes are provided so that the turbine exhaust can pass direct to the chimney without going through the water heater. Some of a turbine's exhaust can be made to by-pass the heat exchanger to provide additional heat in the water heaters.

An inter-trip scheme isolates everything except one alternator set linked to the essential services in the event of certain electrical over-load conditions. Two supplementary oil-fired or gas-fired water heaters, each capable of supplying 5,800,000 BTU per hour can be brought into use to augment the supply of hot water. If the air filters become iced-up, dampers in the two spare chambers can be opened to admit unfiltered air to the gallery serving the blowers and turbines.

Guarding Against Explosion Risk

Elaborate precautions have been taken against the risk of fire and explosion from sludge gas. The compressor room is fitted with double doors, has its own ventilating system, and is equipped with instruments for the detection of gas in the air and air in the gas receivers.

Means are also provided for the injection of pyridine, which has a distinctive smell, into the gas main to give warning of a gas escape. Gas detecting instruments are also fitted.

Radioactive tracer serves important function in determining the . . .

Distribution of Carbohydrate Metabolism In Sewage Sand Filters

By GEORGE B. MORGAN and F. W. GILCREAS, Assistant Research Professor and Professor of Sanitary Science, respectively, Earle B. Phelps Laboratory for Sanitary Engineering Research, Department of Civil Engineering, University of Florida, Gainesville, Florida.

RESUME: Chemical and radio-chemical methods were successfully used to study the distribution of carbohydrate metabolism in pilot plant and laboratory scale sand filters. Carbon-14 tagged glucose was selected as the tracer for the studies. Apparent need for ventilation in lower sand levels is shown by loss of BOD removal ability and absence of nitrogen fixation under anaerobic conditions.

■ FOR THE PAST 60 years the intermittent sand filter has provided an effective method for treating the wastes of small towns, industrial establishments, and institutions. This method of treatment consists of passing settled sewage through a bed of sand and collecting the effluent by an underdrain system. If the sand bed is operated properly a clear, sparkling and nitrified effluent is obtained. The method of construction and operation of a sewage sand filter is relatively simple. The mechanism of BOD removal is based on a series of physical and biochemical reactions. As the name implies the first function of the sand is the filtration of sewage to remove suspended solids not eliminated by primary sedimentation. Another function of the sewage sand filter is the biological digestion or absorption and utilization of the dissolved organic matter.

The distribution of bacteria in sand filters appears to follow a pattern. In the upper few inches *Zooglea* and *Flavobacterium* are the predominant organisms.[1] These organisms decompose complex protein and carbohydrate molecules. Part of these compounds are utilized for protoplasm synthesis and stored food. The waste products consist of less complex molecules which are available to the *Alcaligenes* group, the predominant group in the middle portion of the sand filter.[1] Nitrification takes place in the lower portion of the filter. Nitrobacter has simple nutritional requirements and it has been reported that their growth is inhibited by the presence of much organic material.[2] Many workers have reported that most of the organic removal is accomplished in the upper 8 in. of the filter.[3] These reports were based on the removal of BOD and suspended solids.

The purpose of this investigation was to determine the distribution of carbohydrate metabolism in intermittent sand filters by utilizing chemical and radio-chemical methods.

Apparatus

Sand Filters: Three types of sand filters were used. These are as follows:

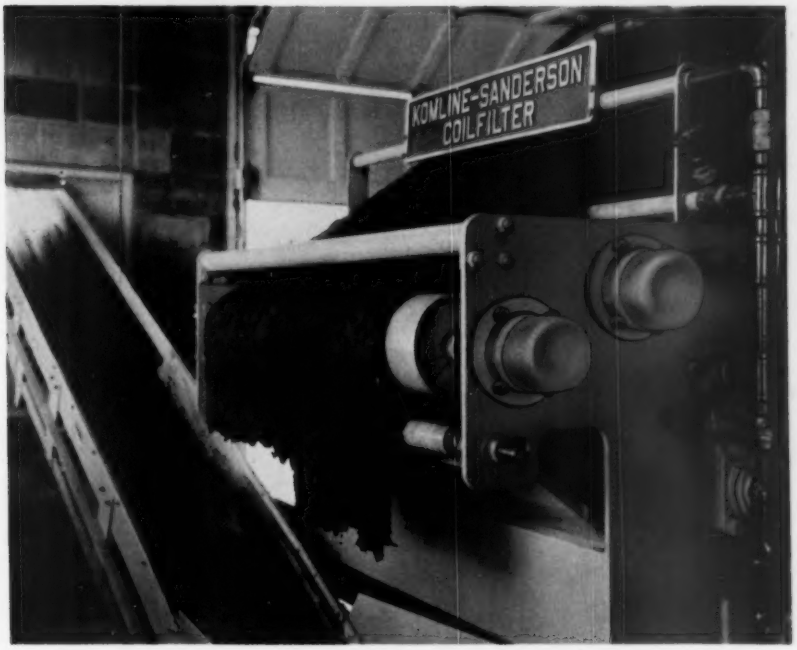
1. Pilot plant filters, 36 in. diameter and 36 in. depth. The sand in these units had an effective size of 0.35 mm and a uniformity coefficient of 1.53.

2. Laboratory scale filters, 12 in. diameter and 12 in. depth. The sand had an effective size of 0.31 mm and a uniformity coefficient of 2.40.

The hydraulic loading on these filters was 200,000 gallons per acre per day and the BOD loading was

KOMLINE-SANDERSON

EQUIPMENT FOR THE SANITARY ENGINEERING FIELD



QUALITY K-S EQUIPMENT

KOMLINE-SANDERSON ENGINEERING CORPORATION

[illegible] JERSEY

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BRAMPTON, [illegible] ONTARIO, CANADA

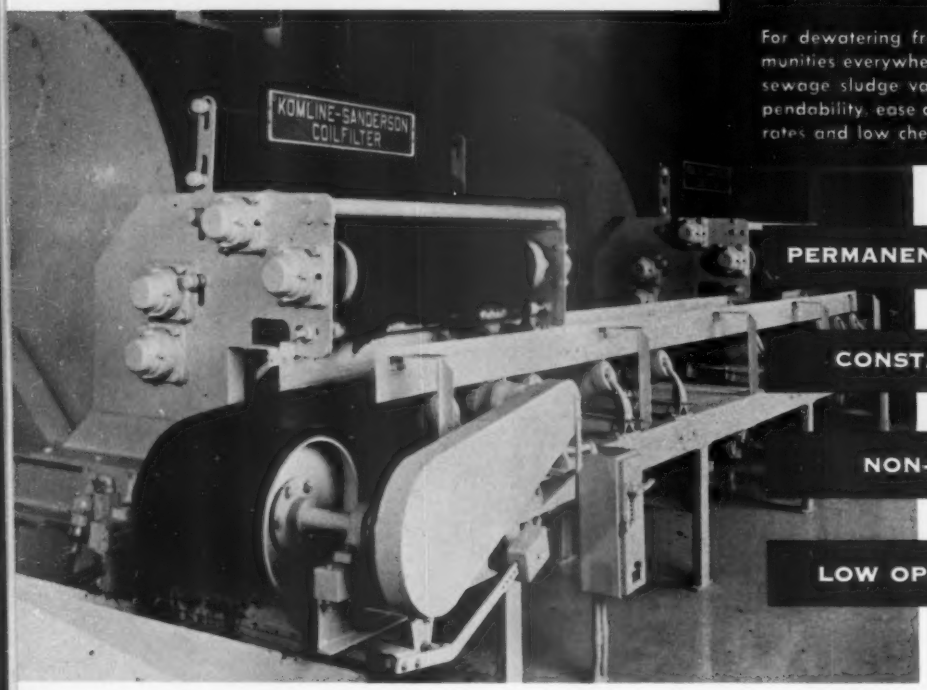
- COILFILTERS
- PNEUMATIC SEWAGE EJECTORS
- DUAL VALVE PLUNGER PUMPS
- DUAL VALVE DIAPHRAGM PUMPS
- PREFABRICATED SEWAGE EJECTOR STATIONS
- PREFABRICATED SEWAGE PUMPING STATIONS
- ROTATING SLUDGE CONDITIONING TANKS
- ROTATING WHEEL CHEMICAL FEEDERS
- ACID PROPORTIONING PUMPS
- GIBBS FLOTATION UNITS
- RECTANGU-LINE SLUDGE COLLECTORS
- NUCLEAR SLUDGE READERS
- ELECTRONIC LIQUID LEVEL CONTROLS
- ZETAMETERS*

* Registered

KOMLINE-SANDERSON COILFILTER

AMERICA'S MOST WIDELY USED SEWAGE SLUDGE VACUUM FILTER

For dewatering fresh solids or digested sludge, communities everywhere are finding the Coilfilter the finest sewage sludge vacuum filter — providing rugged dependability, ease of operation, uniform high production rates and low chemical consumption.



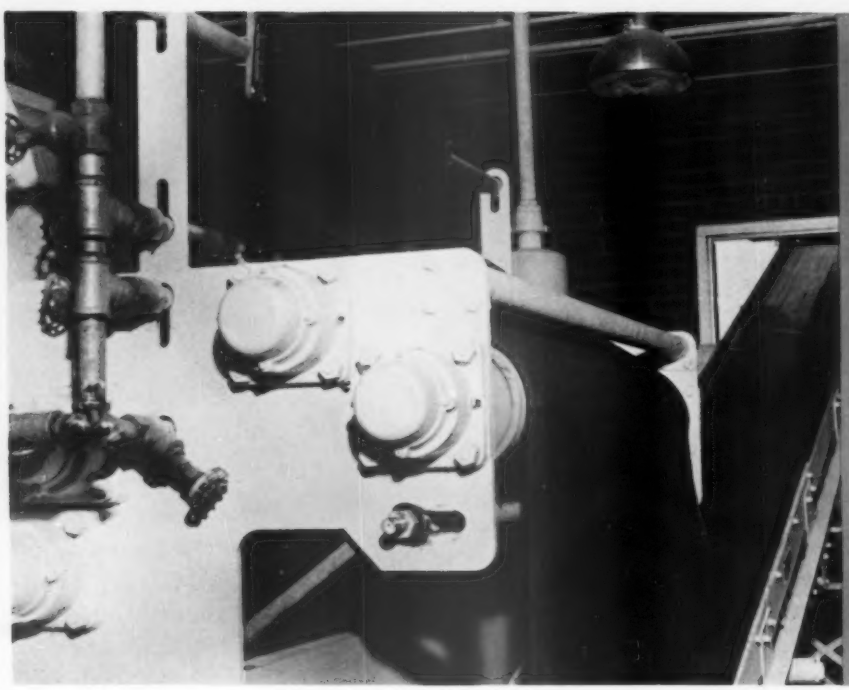
PERMANENT FILTER MEDIA

CONSTANT OUTPUT

NON-CLOGGING

LOW OPERATING COST

Fig. 1



Illustrated on these pages:

Fig. 1 - Upper Merion Twp., Pa. Fresh Solids. Cons. Engineers, Glace & Glace, Inc.

Fig. 2 - Sullivan, Ill., Fresh Solids. Cons. Engineers, Geo. L. Sodemann & Assoc.

Fig. 3 - Norfolk, Neb., Fresh Solids. Cons. Engineers, Lee A. Daly Co.

Fig. 4 - Aurora, Mo. Fresh Solids. Cons. Engineers, Black & Veatch.

Fig. 2

FIRST IN FRESH SOLIDS DEWATERING

The Coilfilter, most successful of all sewage sludge vacuum filters, dewaters both fresh solids and digested sludge with equal facility. The Fresh Solids Dewatering Process is of particular interest to most communities, since it offers the following advantages:

LOWER CAPITAL INVESTMENT

The Fresh Solids Dewatering plant is more compact, requires less land area and fewer structures than a plant with digesters and drying beds.

ECONOMICAL

Fixed charges and operating costs of a Fresh Solids Dewatering plant are lower on a dry solids basis than a plant with digesters and drying beds.

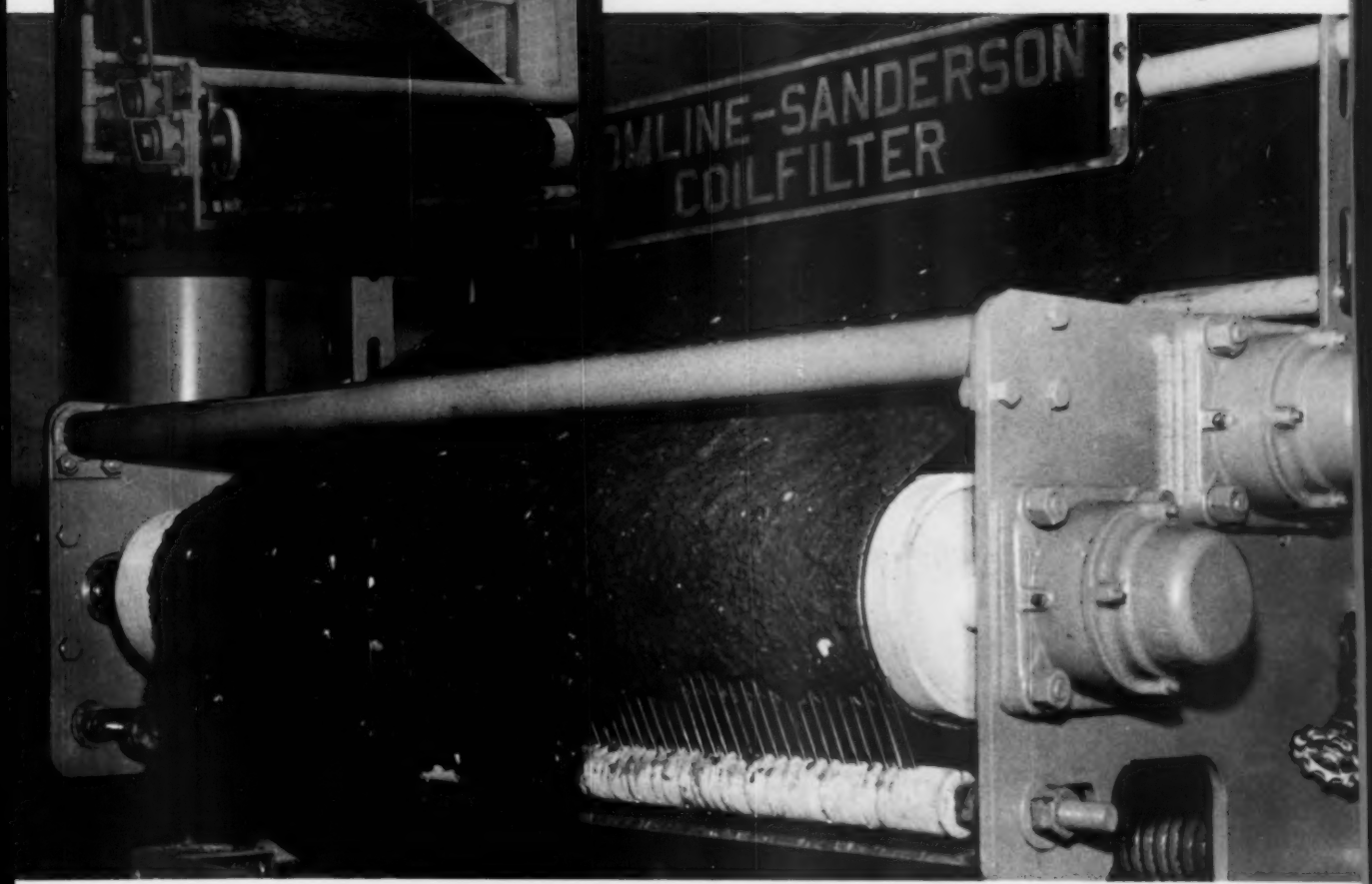
SIMPLE TO OPERATE

With Coilfilter Fresh Solids Dewatering there are no overloaded digester problems. Sludge is dewatered rain or shine, summer or winter. With standard chemical conditioning, dewatered fresh solids do not produce odor or other nuisance.

Komline-Sanderson auxiliaries, designed for the utmost in performance and durability, are manufactured with the same meticulous care as the Coilfilter — backed by K-S service and experience. The following pages describe briefly these products. For further information, please request the bulletins mentioned.

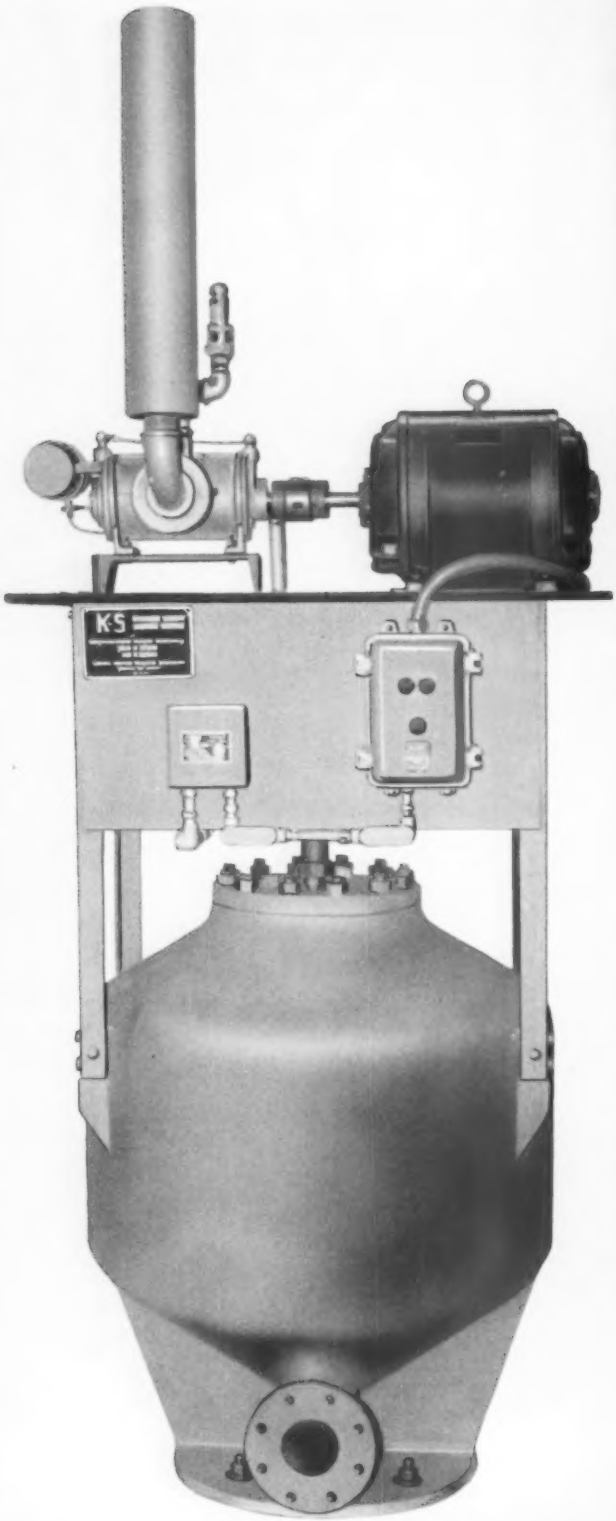
Fig. 3

Fig. 4



ELECTRONICALLY CONTROLLED

PNEUMATIC SEWAGE EJECTORS



Sewage Ejectors are economical sewage pumping stations for relatively low sewage flows. Since Komline-Sanderson ejectors require no wet wells or bar screens, they are ideally suited for installation in basements of buildings, as well as in unattended underground stations. Pneumatic sewage ejectors will handle solids as large as the inlet valves and fittings.

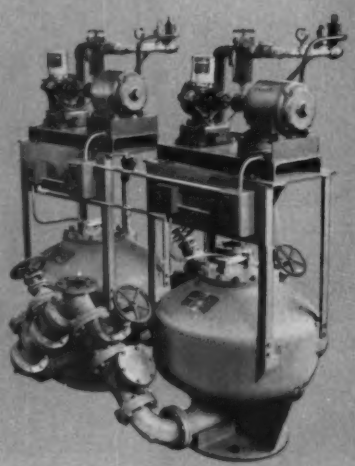
Komline-Sanderson pneumatic sewage ejectors are available from 30 to 600 GPM capacities, in simplex or duplex arrangements, with either cast iron or welded steel pots. These ejectors operate automatically with mechanical (float) or Komline-Sanderson transistorized electronic liquid level controls.

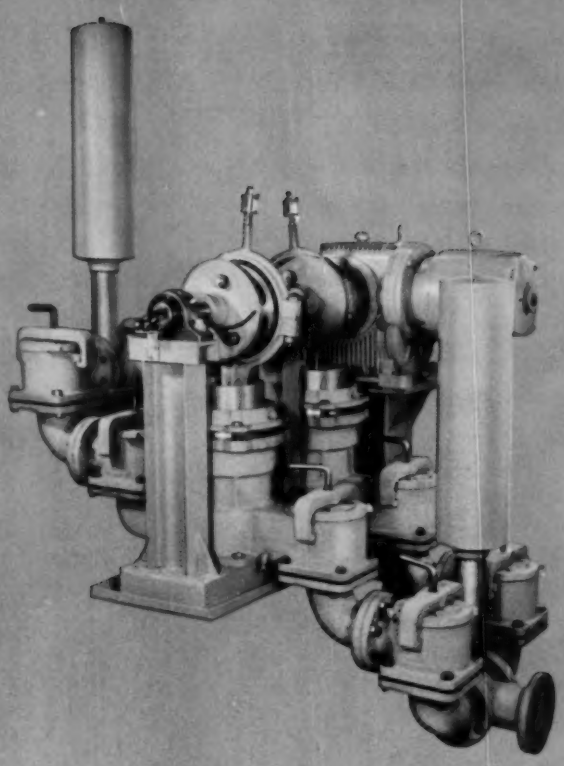
Ejectors can be operated with plant air systems or may be furnished with air compressors.

The large illustration is a single ejector, with cast iron pot, in the "packaged" arrangement.

Shown below is the duplex arrangement.

Write for bulletin No. KSM-2





**"BUILT FOR WEAR—
NOT REPAIR"**

DUAL VALVE PLUNGER PUMPS

Komline-Sanderson Plunger Pumps are specifically designed for pumping sanitary sewage sludge and industrial waste sludges. These pumps are available in simplex, duplex and triplex design (6", 7½", 9" and 11" diameter plungers) with capacities up to 360 GPM.

Although all pumps are also available with single ball check valves, experience has shown that dual valve pumps provide more reliable pumping and metering.

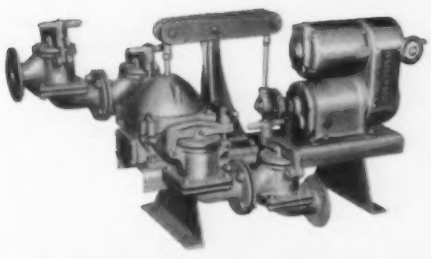
Constant speed motors, with adjustable eccentric for varying capacity, or variable speed motor drives, are available on standard pumps. All pumps incorporate the exclusive, rugged K-S gearing, reducing space requirements to a minimum.

Write for Bulletin No. KSP-3

DUAL VALVE DIAPHRAGM PUMPS

Komline-Sanderson Dual Valve Diaphragm Pumps are available with 2" and 2½" flanged connections, with capacities up to 20 GPM and heads to 25 feet. Both sizes have pump body cleanout handhole, variable speed drive and three position crank. Pumps are ideally suited for pumping slurries, such as lime and some industrial and sanitary waste sludges.

Write for Bulletin No. KSP-4

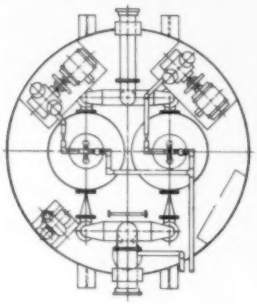


PREFABRICATED SEWAGE EJECTOR STATIONS

Available with either cast iron or welded steel ejector pots, simplex or duplex arrangement. All stations provide maximum accessibility to all valves and auxiliaries. The ejector stations are most popular for sewage flows up to 150 GPM, but are available in larger capacities. Furnished with either electronic or mechanical (float) control, the stations can be supplied with air compressors mounted in the station or for operation on a central air supply.

Komline-Sanderson ejector stations are equipped with sump pump, blower, dehumidifier, lights and other necessary appurtenances, completely piped and wired at the factory.

Write for Bulletin No. KSM-3.



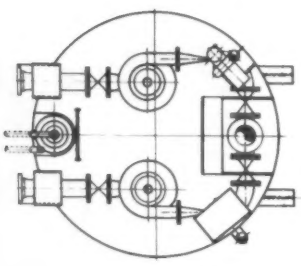
PLAN

PREFABRICATED SEWAGE PUMPING STATIONS

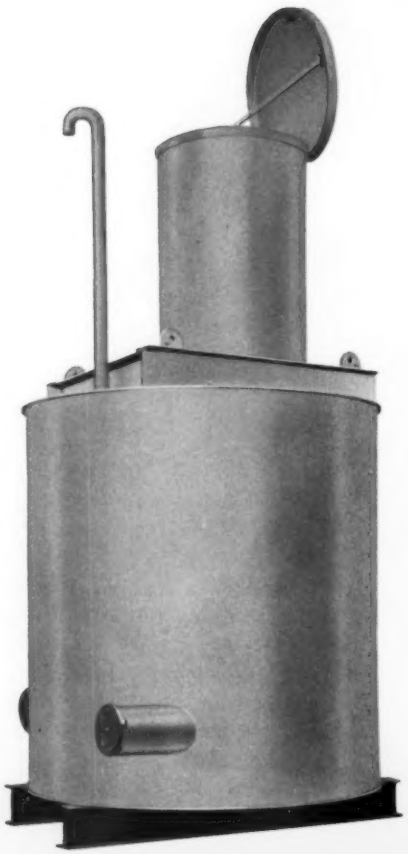
Standard stations incorporate two constant speed, vertical, "non-clog" sewage pumps, motors, bubbler type controller, sump pump, dehumidifier, blower, lights and auxiliaries, piped and wired at the factory. Available for capacities up to 2500 GPM. Special stations can be furnished with variable speed pumps.

Standard stations supplied in 7′, 8′ or 9′-6″ diameter, with the entrance tube furnished in lengths to meet the required elevations for each installation.

Write for Bulletin No. KSM-5



PLAN



ROTATING SLUDGE CONDITIONING TANKS

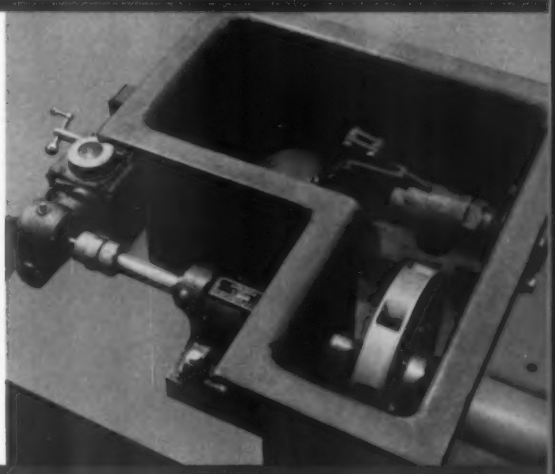
Stainless steel construction, with variable speed drive. Komline-Sanderson Rotating Sludge Conditioning Tanks provide intimate mixing of sludge and conditioning chemicals by gentle agitation during a controlled detention period, assuring optimum filtration rates.

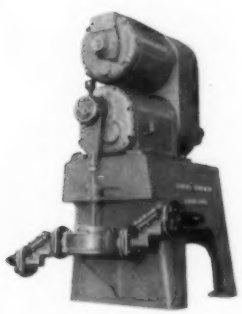
Write for Bulletin No. RT

ROTATING WHEEL CHEMICAL FEEDERS

Suitable for metering most chemicals and slurries where extreme accuracy is desired over a wide range of flows. Capacity to 300 GPH and adjustable within that range to ±2% accuracy. Rate of flow is controlled and adjustable by means of a variable speed transmission with micrometer indicator.

Write for Bulletin No. KSP-4





ACID PROPORTIONING PUMPS

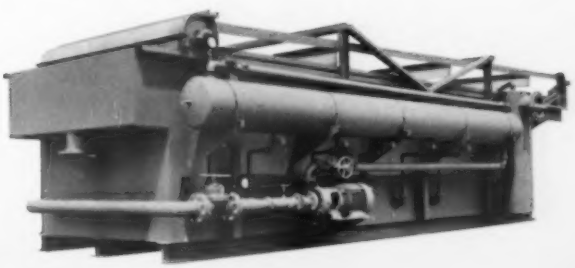
Dual valve design for positive pumping action. Pump and valve bodies are molded kralastic and all metal parts in contact with the pumped liquid are Hastelloy C. Komline-Sanderson Acid Proportioning Pumps are ideally suited to acid and chemical feed applications. Also available in duplex arrangement, providing twice the capacity range.

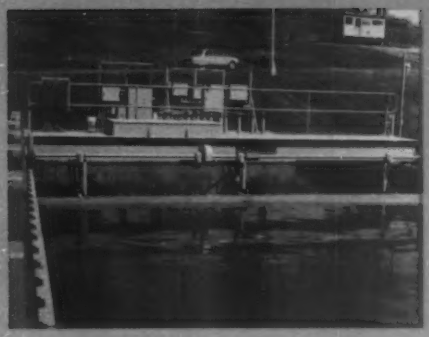
Write for Bulletin No. KSP-4

GIBBS FLOTATION UNITS

Manufactured and distributed by Komline-Sanderson. The flotation unit is self-contained, compact and "packaged" for minimum installation cost. This dissolved air flotation unit is an efficient method of removing fats, oils, food processing wastes and greases from many applications. Seven standard sizes available, from 15 to 250 Sq. Ft. area and flows to approximately 750 GPM.

Write for Bulletin No. KSG





RECTANGU-LINE SLUDGE COLLECTORS

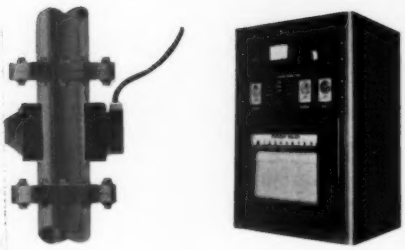
Traveling bridge type sludge collectors supplied for tank widths from 25 to 75 feet and are practical for lengths up to 300 feet and more. Komline-Sanderson Rectangu-Line collectors are self-propelled motor driven, with all machinery and mechanical controls mounted on the bridge, for inspection and servicing. These units automatically stop, start and reverse, collecting the sludge when traveling in one direction and removing tank scum in the other.

Write for Bulletin No. KSM-8

NUCLEAR SLUDGE READERS

For the automatic maintenance of proper sludge and slurry flow consistencies passing through pipe lines. Utilizing harmless nuclear energy, the Sludge Reader reacts to changes in soilds concentrations passing through the line and will, at a predetermined consistency, start or stop the pump. The Komline-Sanderson Sludge Reader contains a radioactive source and detector in a completely shielded housing.

Write for Bulletin No. KSM-7



ELECTRONIC LIQUID LEVEL CONTROLS

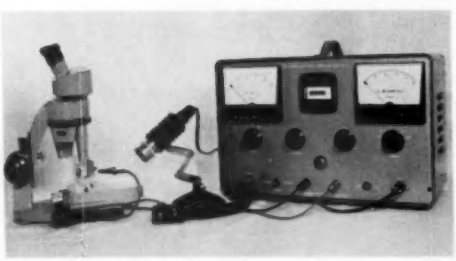
Transistorized, compact, reliable. Capable of operation over a wide range of liquid resistance. Continuously variable control, calibrated directly in seconds (from 0-70), providing fast and easy adjustment of relay "on" time. Available also with high level alarm, transistorized, but battery operated, to energize a light or bell when electricity fails or a high water level is reached due to other malfunctions.

Write for Bulletin No. KSM-6

ZETAMETERS*

The latest development in liquids clarification. The Komline-Sanderson Zetameter is used for measuring the electrical potential of colloidal particles in liquids. Once this measurement is made with the Zetameter, it is possible to treat the liquid with a control additive that will reduce the charge practically to zero, permitting the colloids to coagulate and precipitate.

Write for Bulletin No. KZ-1



* Registered

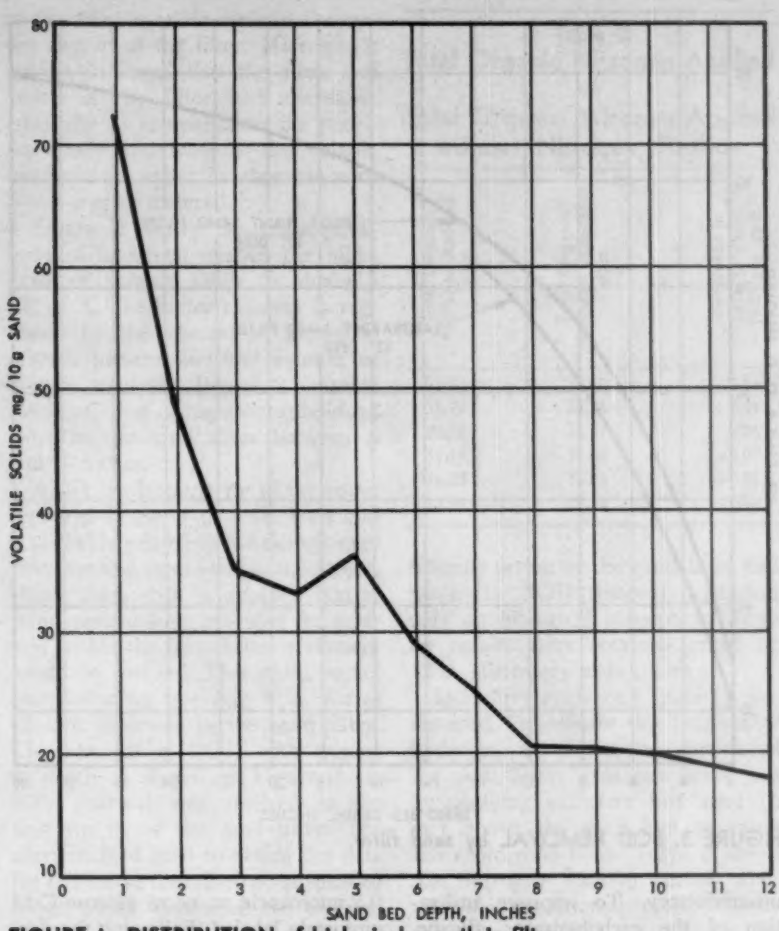


FIGURE 1. DISTRIBUTION of biological growth in filter.

325 lbs. per acre per day. All sand beds were biologically mature at the time of the study.

Counting Apparatus: A Nuclear-Chicago Model D-47 internal proportional flow counter in series with a 192-A ultrascaler, C110-B automatic sample changer, D-47 preamplifier and a C111-B printing timer was assembled for radioactive measurements.

Special Reagents

Glucose-C^{14} uniformly labeled was the carbohydrate selected for this investigation.

Methods and Procedures

Distribution of Biological Growth

Accumulation of volatile solids in the sand filter were considered to be an index of biological growth. To ascertain these values the pilot plant sand filter was cored with a two in. tube. The core was subdivided into 1 in. sections. The weight and volume of the sand section and organic material was obtained by measuring the displacement of water by the sand, then drying and weighing the sand. The dry sample was ignited at 600°C for 30 minutes, cooled and reweighed. The biological growth was calculated as mg of volatile solids per 10 grams of sand. Results are presented in Figure 1.

Buffer Capacity

The buffer capacity per unit volume of volatile solids was used to measure the organic acids produced by the decomposition of organic compounds. The buffer capacity is defined as the milliequivalents of hydrogen ions needed to raise the acidity of an aqueous suspension containing 1 mg of volatile solids to pH 3. Core samples were used and volatile solids were determined as in the previous paragraph. Results are presented in Figure 2.

BOD Removal

The 12 inch laboratory filter was employed to study BOD removal with respect to depth. An artificial sewage containing no suspended solids was the nutrient for this study and consisted of 0.075 g each of glucose, peptone and powdered milk

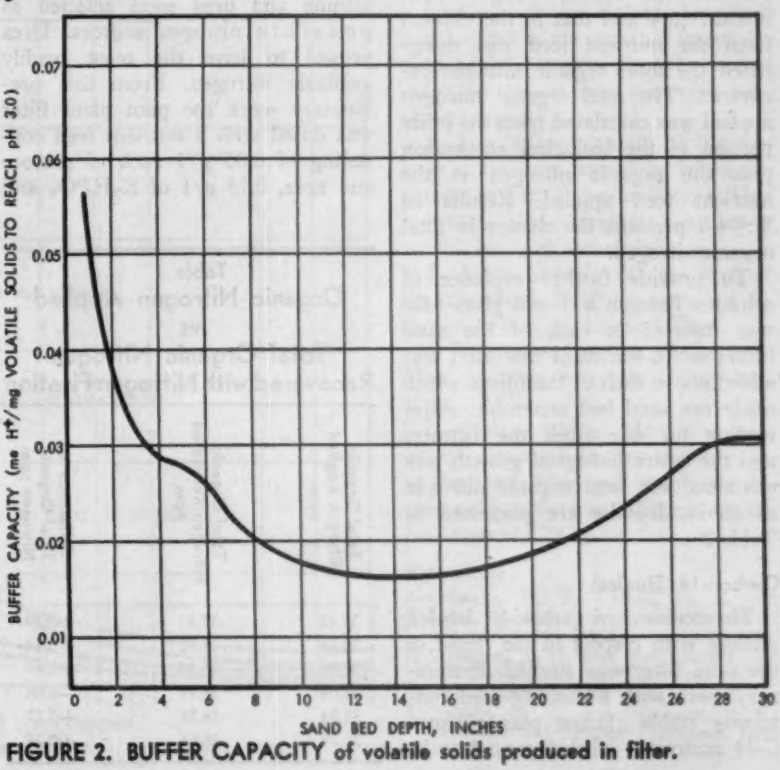


FIGURE 2. BUFFER CAPACITY of volatile solids produced in filter.

dissolved in 1200 ml of BOD dilution water. This solution exerted a BOD of 252 ppm. This nutrient food was also applied to a series of pilot plant sand filters of varying depths up to 30 inches. Results are presented in Figure 3.

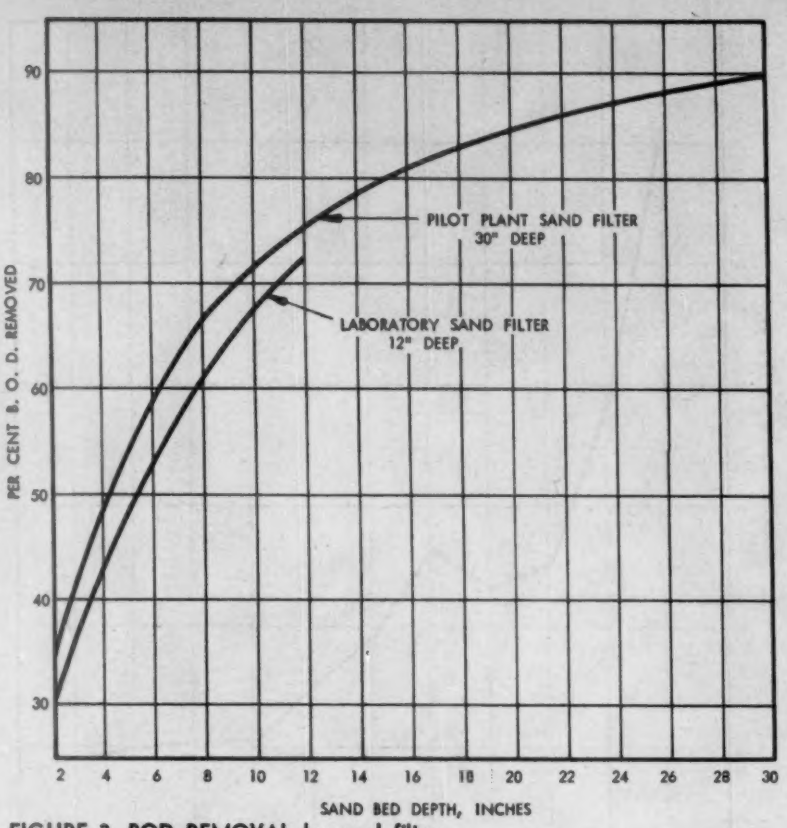


FIGURE 3. BOD REMOVAL by sand filter.

Total Nitrogen Removal

Laboratory scale sand beds of 2 in. diameter and 12 in. depth were the agencies for measuring the organic nitrogen removed. During this study results were obtained that indicated fixation of organic nitrogen. To study this further six replicate filters were constructed of glass tubes ¾ in. diameter by 12 in. long and filled with washed silica sand. Biological growth was extracted from a biologically mature sand filter, emulsified and divided into two portions. On one portion total organic nitrogen was determined and the other portion was filtered through the sand filters. The final effluent was filtered through the filter several times to insure optimum extraction of microorganisms from the suspension. The filtrate was examined for total organic nitrogen. After dosing the sand filters for three days, the total organic nitrogen content of the effluent and the organisms in the sand was determined. This value plus the total organic nitrogen in the initial liquor and that in the effluent from the nutrient feed was designated the total organic nitrogen recovered. The total organic nitrogen applied was calculated from the other portion of the biological suspension plus the organic nitrogen in the nutrient feed applied. Results in Table 1 presents the change in total organic nitrogen.

To provide further evidence of ntirogen fixation a 3 mm glass tube was inserted in each of the sand filters and 6 inches of fine sand was added above each of the filters which made the sand bed anaerobic. After feeding for one week the filtrates and the entire biological growth was examined for total organic nitrogen as above. Results are presented in Table 2.

Carbon-14 Studies:

The removal of carbon-14 labeled glucose with respect to the depth of the sand filter was studied. Preliminary work with a nutrient feed containing stable glucose plus glucose-C-14 uniformly labeled proved to be unsatisfactory. To improve utilization of the carbohydrate; glycine, alanine and urea were selected as possible nitrogen sources. Urea proved to have the most readily available nitrogen. From this preliminary work the pilot plant filter was dosed with a nutrient feed consisting of 0.05 g/1 each of glucose and urea, 0.15 g/1 of K_2HPO_4 and 0.5 microcurie = uc of glucose-C-14 uniformly labeled. Following the dosing, a 2 in. core 12 in. long was removed after 0.2, 4, 8 and 18 days. The carbon-14 activity was determined on each 1 in segment. Over a period of 3 months four replicate experiments were performed and the average results are presented in Figure 4.

Table 1
Organic Nitrogen Applied vs Total Organic Nitrogen Recovered with Nitrogen Fixation

Total Organic Nitrogen Applied ppm	Total Organic Nitrogen Recovered ppm	Difference in Total Organic Nitrogen ppm
37.42	37.81	+0.39
30.68	31.82	+0.14
35.27	35.68	+0.41
35.04	34.99	−0.05
35.94	36.21	+0.27
36.39	36.64	+0.25

Results and Conclusions

The results from this investigation show that most of the treatment by sewage sand filters is realized in the upper 5 or 6 inches. Figure 1 shows that at the 5 inch level there is an abrupt change in the concentration of volatile solids. A similar distribution of volatile solids has been observed in several other sand filters. From the microscopic examination of the flora and fauna of the sand bed it appears that in the depth range of 4 to 6 inches microaerophilic conditions exist. Following the termination of this study the sand bed was loaded at a rate of 400,000 gad. After the bed was clogged the distribution of the volatile solids was again determined. It was observed that most

of the volatile solids were in the upper two in of the filter. Microscopic studies indicated that the flora and fauna in the filter had decreased markedly as compared to the previous study and most of the volatile matter in the upper 2 inches was nonliving organic material.

Figure 2 shows the milliequivalents of hydrogen needed per milligram of volatile solids to obtain a pH of 3. The buffer capacity is regulated by the amount of biological growth present and the amount of oxygen available. Figure 2 presents evidence that anaerobic conditions exist in the sand filter between 6 and 24 inches.

Again, an irregularity in the curve appeared at the 4 to 6 in. level and is probably related to the change over from aerobic to anaerobic conditions. From these data it appears that if some method were provided for aeration within the filter better treatment would be realized. This could be accomplished by inserting 4 in. tile at 12 inch intervals in the sand filter. The removal of BOD with respect to depth is shown in Figure 3. A 60% removal was realized in the first six in. of the sand filter. The nutrient feed used to obtain the data for this curve contained no suspended solids which eliminated the physical filtering action of the sand filter and made the BOD removal dependent only on biological absorption. Similar results were obtained using the 12 in. laboratory scale filter.

Table 2
Total Organic Nitrogen Applied vs Total Organic Nitrogen Applied without Nitrogen Fixation

Total Organic Nitrogen Applied ppm	Total Organic Nitrogen Recovered ppm	Difference in Total Organic Nitrogen ppm
36.54	36.50	−0.06
35.72	35.76	+0.04
35.36	35.31	−0.05
37.14	37.08	−0.07
36.82	36.83	+0.01
37.28	37.18	−0.10

Definitive evidence (Table 1) was obtained to indicate the fixation of hydrogen in the upper portion of the sand filter. This was borne out by applying sufficient fine sand (6 in.) above the sand bed to cause anaerobic conditions. Table 2 shows that nitrogen fixation ceased when anaerobic conditions prevailed. Nitrogen fixing bacteria, presumably *Azotobacter*, are present in the upper layers of a sewage sand filter in sufficient quantities to fix in the neighborhood of 100 lbs. of nitrogen per acre per year. Certainly this evidence of nitrogen fixation indicates that further work is needed.

Figure 4 shows that most of the absorption of carbon-14 labeled glucose was realized in the upper six in. of the sand filter. Radioanalysis of the gasses from the filter showed that over an 18 day period 26 per cent of the carbon-14 was evolved as carbon dioxide. The remainder including the final effluent of the initial dosing was collected as soluable wastes. The evolution of CO_2 further indicates that most of the biological activity occurs in the upper layers because if the carbon dioxide were evolved in the lower portion it would be dissolved in the entrapped water and appear in the effluent.

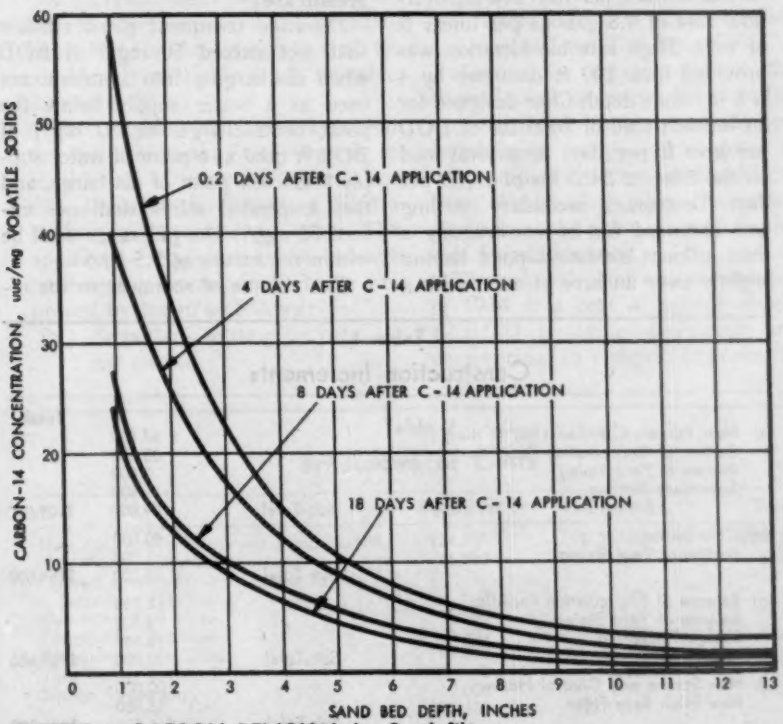


FIGURE 4. CARBON REMOVAL by Sand filter.

Summary

The distribution of carbohydrate metabolism was studied to determine the fate of carbohydrates in intermittent sewage sand filters. These studies were carried out using a nutrient feed without suspended matter which eliminated the physical removal of BOD The following results were found:

1. Most of the biological growth was located in the upper 6 in. of the sand filter. Microscopic examination indicated that at 6 in. anaerobic conditions began.
2. The buffer capacity of the bed is at a minimum from 6 in. below the surface to 2 in. above the bottom. This indicates that internal ventilation would be very beneficial.
3. Approximately 60 per cent of the dissolved BOD is removed by the upper 6 in. of the sand filter.
4. The upper portion of the sand filter contains nitrogen fixing bacteria.
5. Carbon labeled glucose is primarily absorbed in the upper 6 in. of the sand filter and undergoes decomposition there as indicated by the evolution of $C^{14}O_2$.

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3. Babbitt, H. E., and Baumann, R. E., *Sewerage and Sewage Treatment*, John Wiley, New York, P. 519 (1952).

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Automatically Controlled Variable Speed Pumping

by V. A. VASEEN, Pres.
Ripple & Howe, Inc.
Consulting Engineers
Denver, Colo.

EDITOR'S NOTE: Shortly after completing its treatment plant the North Washington Street Water and Sanitation District was faced with the fact that a revision of the State Health Department standards required major improvements in their plant if the new effluent standards were to be met. Growth in the population of the District which is located outside Denver also indicated that expansion of the plant's capacity would also be advisable when construction was done to meet the new state requirements. Original estimates of the cost of both the expansion and the changes necessary to raise the effluent quality were $341,000. By replacing the original plans for a set of fixed output pumps of various outputs with variable speed pumps and utilizing automatic control sensing the level of the pump sumps it was possible to reduce the estimate to $270,000 and not increase estimated operating costs.

■ IN MARCH 1954 the North Washington Street Water and Sanitation District submitted plans and specifications to the Colorado State Board of Health for a complete sewage treatment plant with a design flow of 1 mgd, based on a 16-hour day. The design was for a population of 12,000 persons, having a per capita water use of 70 gpcd.

Existing Plant

This design consisted of screening and grinding facilities for a plant of 5 mgd capacity. This equipment was laid out with the thought in mind that at some future capacity, it might be desirable to move this screening and grinding equipment to another structure, to make room at its location in the control building for standby power equipment. Primary clarification was provided in one 65 ft diameter x 7 ft 6 in. side water depth clarifier, sized to meet design requirement with a 1 to 1 recirculation of filtered effluent, a total flow of 2000 gpm. At the 1 to 1 recirculation rate the clarifier has a detention period of one hour and thirty four minutes; a settling rate of 577 gallons per square foot of surface per day and an overflow rate of 9.8 gallons per linear ft of weir. High rate bio-filtration was provided in a 100 ft diameter by 4 ft 6 in. stone depth filter designed for an influent load of 2000 lbs of BOD per acre ft per day, or a total load on the filter of 2450 lbs of BOD per day. Temporary secondary settling was arranged for by constructing a final effluent oxidation pond having slightly over an acre of area, with a maximum design loading approximately 477 lbs of BOD per day. If the pond needed additional dissolved oxygen it could be introduced by adding to the pond irrigation water containing dissolved oxygen.

New State Requirements

On January 14, 1957, the Colorado State Board of Health raised the standards which will be required by sewage treatment plant effluents in the State of Colorado and gave the communities and sanitation districts within the state until January 1, 1958 for compliance. The new requirements of the Colorado State Board of Health are:

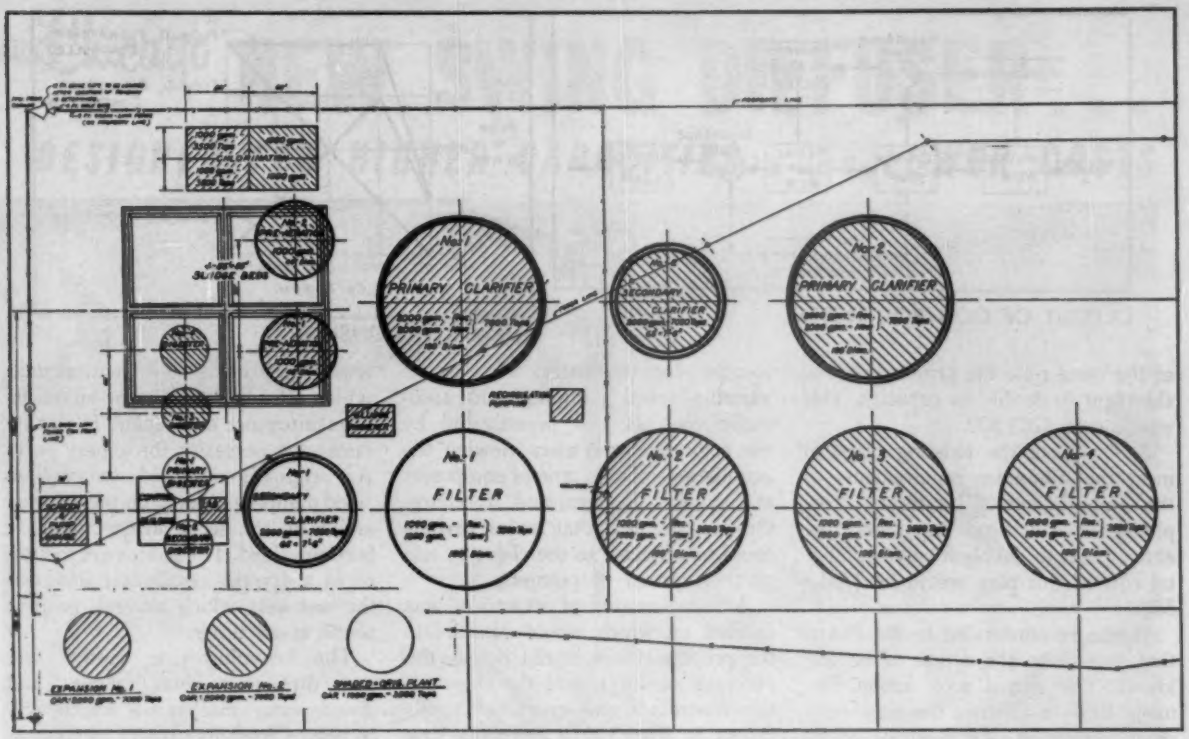
"Sewage treatment plant effluent shall not exceed 50 mg/l of BOD when discharging into a stream not used as a water supply below the point of discharge, or 30 mg/l of BOD if used as a point of water supply below the point of discharge, and that suspended solids shall not exceed 75 mg/l. The pH range shall be within the values of 5.5-10.6.

The volume of sediment in the ef-

Table I

Construction Increments

			Totals
1st	New Primary Clarifier (100 ft diam.)	$ 67,500	
	Portion of Recirculation Facilities	33,500	
	Portion of Yard Piping	7,500	
	Secondary Settling	500	
	Sub-Total	109,000	$109,000
2nd	Chlorination	40,500	
	Portion of Yard Piping	5,000	
	Sub-Total	45,500	$154,500
3rd	Balance of Recirculation Facilities	12,300	
	Balance of Yard Piping	2,500	
	Sludge Thickening	16,500	
	Sub-Total	31,300	$185,800
4th	New Screen and Control House	100,000	
	New High Rate Filter	55,500	
	Sub-Total	155,500	$341,300



PROPOSED Expansion Plant Layout

fluent shall not exceed 0.5 ml when the test for settleable solids, by volume, is made in accordance with Standard Methods for the Examination of Water & Sewage, Ninth Edition. For the purpose of these regulations, blood and meat scraps shall be considered settleable and floatable substances."

The original plant was approved by the Colorado State Board of Health, as a "complete" plant, but this *action* of the Board of Health made it an "intermediate" plant. The additional requirements of sewage treatment plant require it to be improved in design as follows:

a) Secondary settling by mechanical means.

b) The final effluent to be chlorinated with a content period of not less than 15 minutes based on maximum hourly flows and also be able to discharge an effluent having a chlorine residual of from 3 to 5 mg/l.

Due to the arrangement of the original plant structures the state felt it would be advisable to provide new recirculation pumps and controls, in order to permit return of the effluent from the trickling filter to varying elements of the plant, as well as provide for chlorination.

The original plant was constructed in 1954 at a cost of approximately $200,000 including equipment and engineering. In order to improve the plant to minimum State Health Department requirements would require a new secondary clarifier 45 ft in diameter for $24,000; chlorination, super-structures and automatic chlorinator $30,500, recirculation pumps, wet pit and super-structure building, piping, valves, mechanical, and automatic controls $38,500; and miscellaneous piping in the yard $10,000, for a grand total of $103,000. Following these expenditures, the plant would have an effluent which would comply with the standards, but the plant itself would be at variance with their requirements in several respects.

Table 2

Breakdown of Costs

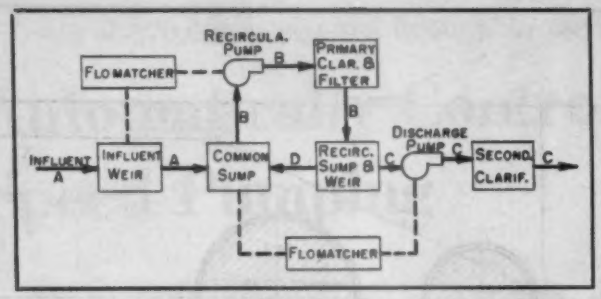
	Equipment	Contract	Total
New grit, screen house and pump station	$24,600	$ 75,400	$100,000
New Primary Clarifier	16,000	51,500	67,500
Convert existing Primary Clarifier to Secondary Clarifier	0	500	500
New High Rate Filter	5,000	50,500	55,500
Chlorination Facilities	6,000	34,500	40,500
Recirculation Facilities	11,800	34,000	45,800
Yard Piping Revisions	0	15,000	15,000
Sludge Thickening	7,000	9,500	16,500
TOTAL	$70,400	$270,900	$341,300

Expansion Plans

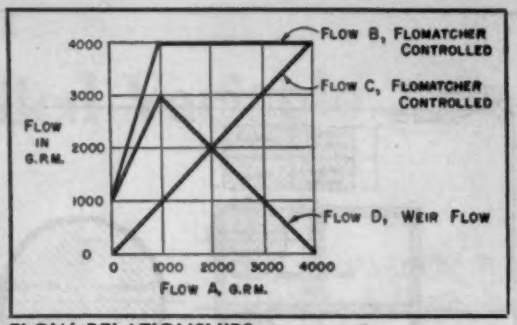
Following the action by the Board of Health, the Board of Directors of the District, authorized the authors firm to prepare a report on possible solutions to the problem. The report was presented to the Board in September, 1957 and recommended the following three alternate plans of action:

1. Complete the existing plant to meet the minimum requirements for the present design population. This would cost approximately $100,000.

2. Complete the plant to meet Health Department requirements and



LAYOUT OF CONTROL SYSTEM.



FLOW RELATIONSHIPS

at the same time the primary part of the plant to double its capacity. This would cost $263,500.

3. Complete the existing plant to meet the minimum requirements of the State Board of Health by completely revising and expanding the entire plant to double it capacity. Total cost of this plan would be $541,-300.

It was recommended to the Board that plan 3 be the action to be followed. The Board took action October 1957 to approve the engineer's recommendation. As a means of financing the Board adopted a regulation requiring an aditional $100.00 per tap connection fee over and above the $150.00 being collected to pay for sewer lines. The extra $100.00 to be placed on deposit until sufficient funds were collected or additional funds could be added to those collected to expand the plant.

The Colorado State Board of Health in reviewing the Report placed restrictions on the Board as follows: 1. that the Board of Directors would in writing, notify the Board of Health, that they were aware of the need of expansion of the Sewage Treatment Plant and 2. that final plans and specifications would be engineered so that by the time financing was available, time would not be lost in having final plans and specifications made.

The plans provided for the expansion were revised in such a way that the Board could, if necessary, construct various portions of the work and ultimately achieve an over-all expansion of the plant. The arrangement of the construction of new facilities and revision of old facilities were as shown in Table 1.

New Design

Programmed pumping with five pumps with capacities from 250 gpm to a total of 5,000 gpm was the basis for the cost estimates. The use of variable speed pumping and automatic controls was investigated by the engineers who after viewing the installations of this type of equipment at Corvallis, Eugene, and Roseburg, Oregon, deciding that major savings could be afforded to the client by use of this system of pumping.

A re-orientation of structures was decided on which would consolidate the proposed new screen house, the pumping facilities, and the chlorination controls in one structure. Details shown in Fig. 1. All incoming raw sewage from both the main 24-in. outfall sewer from the south and the 24-in. outfall sewer from the north were collected in one 33 in. main at the plant site. The raw sewage discharges into the west, wet pit ahead of the pumping controls. From the wet pit the sewage overflows over a weir to the sump for the raw sewage lift pumps.

The height of flow over this weir controls the speed of two 75 hp two 2000 gallon per minute maximum, variable speed pumps, driven by wound rotor motors 700 rpm to 1000 rpm through variable controls. The incoming sump has a sluice gate at the bottom so from time to time any solids which might occur in the sump can be flushed. A feaure of the design is that any "flood" conditions, that is excessive flows over and above maximum capacity of the raw sewage pumps, cause the water level to rise and overflow into the re-circulation wet pit on the east side of the pump sump. At this level the re-circulation pumps to the secondary settling tank thus guarantee at all times at least primary treatment. This is made possible by the elevation control in the recirculation wet pit which automatically close the re-circulation control valves and transfer the flow to the secondary settling tank.

The pumping for the entire sewage treatment plant is by 4 identical units which affords the operator simplicity of maintenance and repair. It also reduces the necessity for repair parts. As originally designed, ten various sized pumping units, 5 on the primary and 5 on the secondary would have been provided. The pumps are mounted in a dry pit installation alongside the wet pits which assures positive prime at all times.

The incoming raw sewage will pass through a rotary screen, and disintegrator mechanism which will be moved from its present location in the digestor control building to its new location on the west side of the new structure adjacent to the wet pits. A feature of the design of this building is the isolation of the screening and grinding facilities from the balance of the building. A plate glass window affords the operator a full view of the entire operation and yet restricting odors to that part of the building which has its own ventilation system separate from that of the remaining portion of the building.

The ground floor level of the building houses four one ton chlorine tanks, along with two automatic chlorinators, which can be used for either pre-chlorination or post chlorination. If necessary they can be used in parallel for either "pre" or "post" chlorination. The grit will be removed from the sludge by use of a centrifugal separator, prior to sludge being thickened. The grit will be washed prior to the discharge by means of a screw type classifier which discharges through the wall of the building to storage buckets pending final disposal.

The top floor of the building, or the second story above grade, will be completely glass enclosed. Here will be housed the control cabinet, files and other equipment required by the operator. In this control room a view

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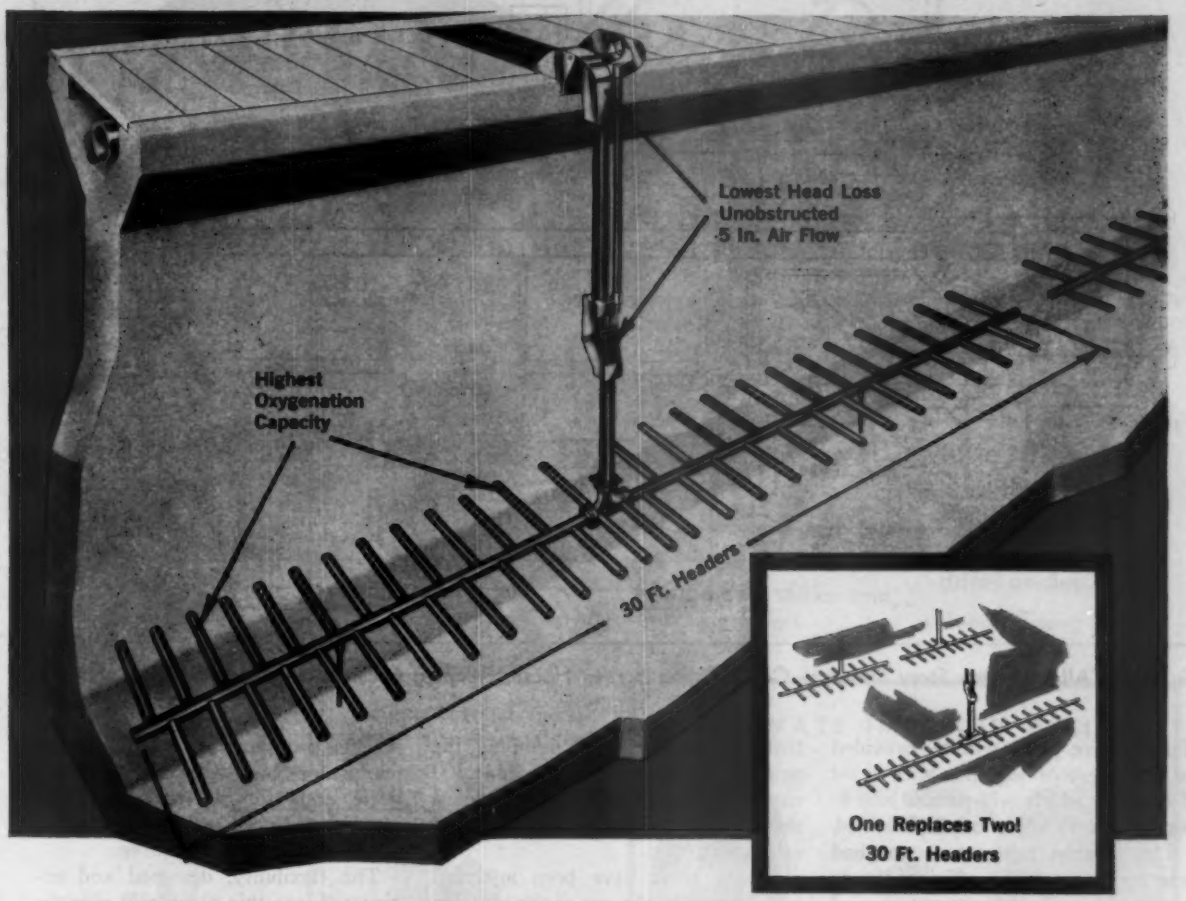

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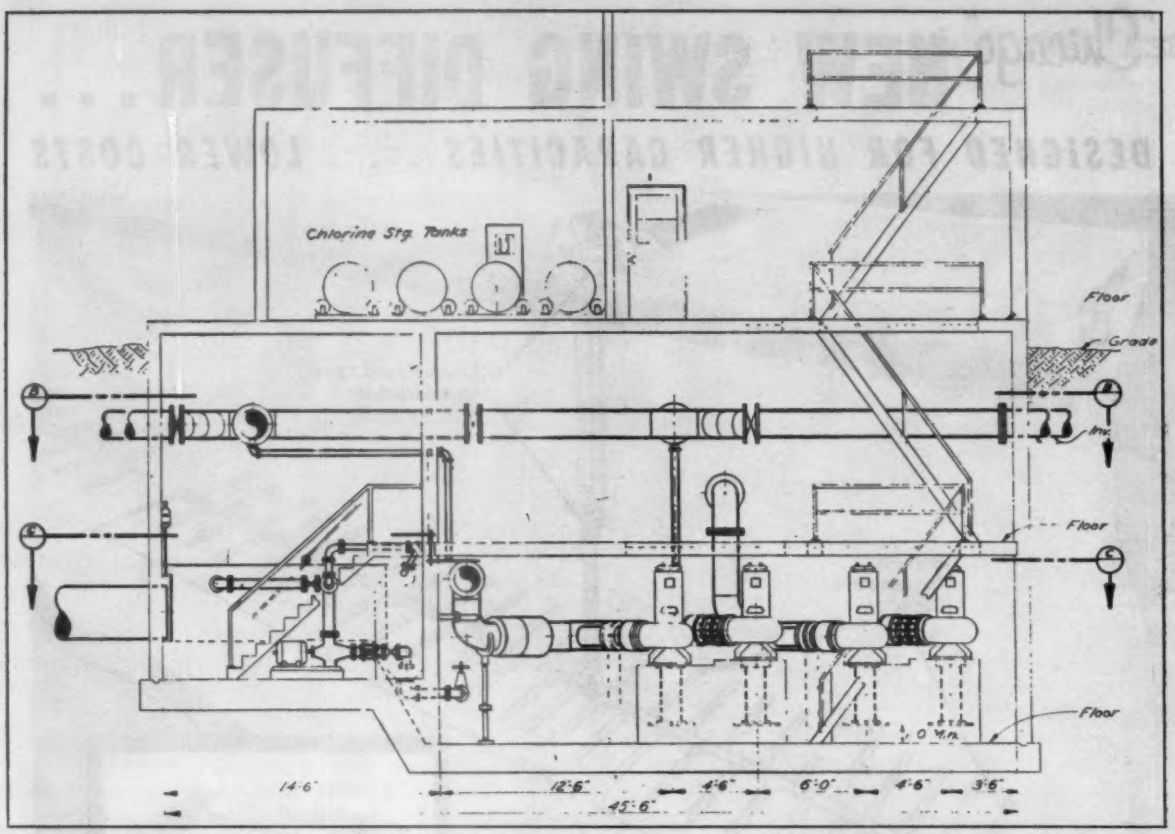

Fig. 1 DETAILS of One Story Structure Consolidating Screen House, Pumping Facilities and Chlorination Controls

of the entire plant will be provided for the operator together with a set of controls which will permit him to stop, start and adjust any operations.

The District has not as yet had time to accumulate sufficient funds to proceed with the construction of the plant, but from an analysis of the cost of the structures involved, it is believed that through the use of this composite structure along with controls and variable speed pumping, the original estimated cost of $341,300 can be reduced to $270,000. Table 3 shows a breakdown of the new cost estimate.

Power costs have been analyzed with regard to the use of the variable speed units and it is expected that the total overall efficiency of pumping will be for all practical purposes the same as it would have been when using five programmed, varied capacity pumps, for the raw sewage, with duplicate units for re-circulation. This can be evidenced on examination of the attached pumping curve.

The flexibility, designed and engineered into this plant, will give the sewage plant operator a maximum control of the handling of both the raw influent sewage to the plant as well as the return of primary or secondary effluent to re-circulation. The raw influent to the plant contains waste from five meat packing plants, and at times runs as high as 1500 mg/l of BOD. Many times it averages for several hours in excess of 500 mg/l of BOD. As a result it takes extreme flexibility in order that the plant operator can meet at all times the State Health Department requirements of an effluent which will not contain more than 50 mg/l of BOD.

Table 3

New Breakdown of Costs

Control House and Recirculation Structure	$ 30,000
Controls, including Air Compressor for operating automatic valves	4,000
Pumps and appurtenances, installed	15,000
Piping and Valves, except yard piping	25,000
Automatic Chlorination	8,000
Electrical work, including the relocation of existing control panels	10,000
Boiler and controls	3,000
Flomatcher units and controls	16,000
New Primary Clarifier Tank and equipment	50,000
Sludge Thickening equipment and piping	20,000
Chlorination Retention Tank and Controls	20,000
New Bio-Filters	50,000
Portion of the control house to be used as screen and grinding building and appurtenances, as well as moving existing equipment to its new location	10,000
Degriting Unit and installation	4,000
Complete forced air ventilation of the control and screen house	5,000
Total Cost of Additional Construction	$270,000

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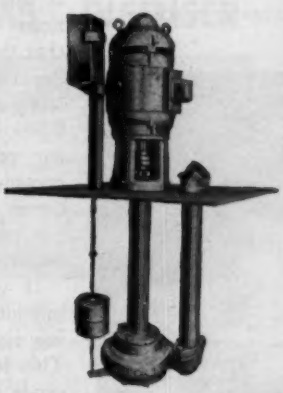

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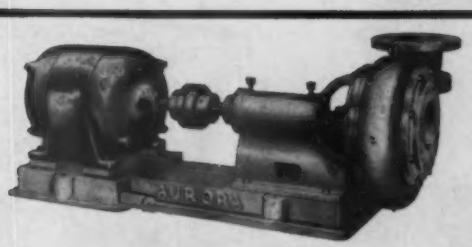

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Lubricating Centrifugal Sewage Pumps

Wearing Rings

by C. E. KEEFER and H. S. BECKER
Sewerage Engineer and Superintendent of Pumping Plants, Bureau of Sewers, Baltimore, Maryland

RESUME: More than eight years work has been expended by Baltimore's Bureau of Sewers to develop a method for adding lubricating oil to the wearing rings of centrifugal sewage pumps. This method utilizes waste oil from the city owned garage, and the lubrication has been successful in keeping the dirt out of the space between the rings, thereby reducing the wear of these rings from about 0.029 to 0.001 inches per billion gallons pumped.

■ ONE OF THE OPERATING CONDITIONS which reduces the efficiency of centrifugal sewage pumps is the increase in the clearance between the suction eyes of pump impellers and the adjacent pump casings due to erosion. Many sewage pumps are provided with bronze or stainless steel wearing rings, one on the impeller and the other on the pump casing, which can be removed and replaced with new rings when the clearance between the rings becomes excessive. A method that has been successfully used at three of Baltimore's sewage pumping stations to greatly reduce this wear has been the introduction of a small quantity of lubricating oil into the space between the rings during pump operation.

Fig. 1. POINT OF ENTRY of oil pipe into pump casing and wearing rings of the centrifugal pump at the Brooklyn Sewage Pumping Station.

Wearing rings of centrifugal pumps are subject to greater wear when pumping sewage than when pumping water. This condition is caused by the high percentage of gritty and foreign materials in sewage. As Baltimore is served by a separate system of sewers, the grit in the sewage is not excessive. From 1950 to 1959 inclusive, the quantity of grit removed from the sewage at the Back River sewage-treatment works, the city's main plant, averaged 1.7 cu ft per mil/gal of sewage. Observations made for several years at three of the sewage pumping stations in Baltimore have indicated that the clearance between the wearing rings of the centrifugal pumps has increased at the rate of 0.029 to 0.044 in. per billion gallons of sewage pumped. As this clearance increases, more sewage flows back between the rings from the high to the low pressure side of pumps and consequently the efficiency decreases.

It was thought that perhaps the introduction of oil between the wearing rings might reduce this erosion. This idea was first tried in a rather crude way on a 30 mgd double-suction centrifugal pump. A small hole was drilled through the pump casing and the bronze wearing ring in the casing. A small brass pipe was fitted into this hole, and an oil cup, equipped with a hand pump, was attached to the upper end of the pipe. Every half hour about one pint of oil was injected into the space between the wearing rings. As a result of several

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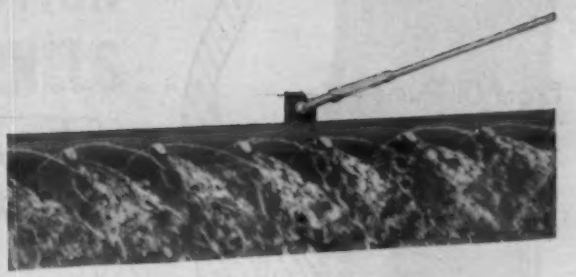

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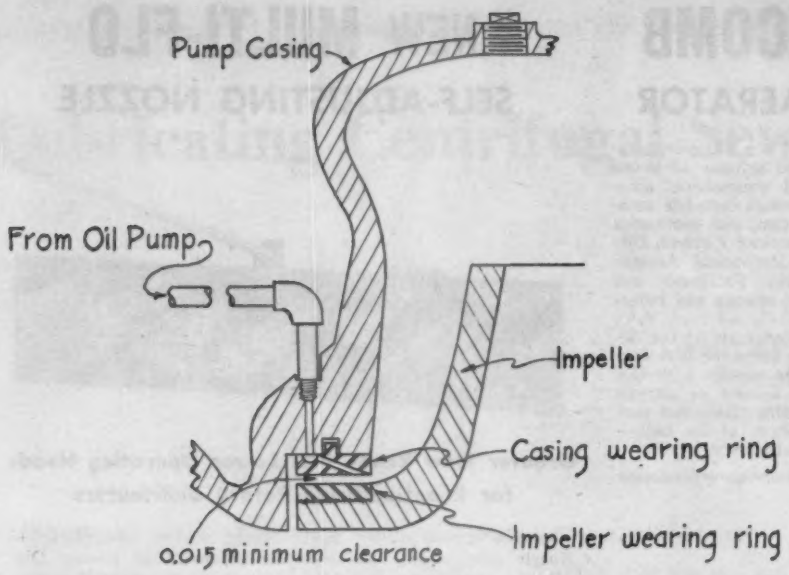

Fig. 2. OIL PIPE CONNECTION to wearing rings of the centrifugal pump.

months of operation, the rings showed less wear and less tendency for solids to accumulate between them. Subsequent to these observations a much more satisfactory way of feeding oil was devised. A small rotary-type displacement pump was fastened to the outboard bearing of one of the centrifugal sewage pumps. The end of the shaft of this pump was provided with a pulley which was driven by a V-belt. This belt engaged a split pulley which was fastened either to the shaft of the sewage pump or its drive motor. An overhead steel tank served as a reservoir for the oil and was connected to each gear pump by ⅜ in. copper tubing. Tubing of the same size connected the pump with the casing of the centrifugal pump at a point near its stationary wearing ring, Fig. 1.

That face of the ring, Fig. 2, which made contact with the pump casing was provided with a semi-circular annular groove which had a radius of ⅜ in. A ⅜ in. diameter hole was provided in the pump casing to permit the passage of oil from the copper tubing to the annular groove in the wearing ring. There were six ⅜ in. diameter holes, spaced equidistances apart in the wearing ring, which allowed the flow of oil from the annular groove to the space between the two wearing rings. These holes entered the space between the wearing rings at a point farthest removed from the suction eye of the impeller. This feature of design permitted the oil to pass over the entire surfaces of the wearing rings when the centrifugal pump was operating. A needle valve in the copper tubing was installed to control the quantity of oil being pumped to the wearing rings. There was also an overflow pipe from the oil pump through which excess oil was pumped back into the oil storage tank. Discarded automobile crankcase oil, was collected from city owned garages, was the lubricant used. The capacity of each oil pump was adjustable from a few drops per second to a little more than 1 gpm. After operating the rotary-type oil pumps for several months, they were found to be unsatisfactory and were replaced by bronze gear pumps, Fig. 3, which have given excellent service.

Each of the centrifugal pumps at the Dundalk and the Brooklyn sewage pumping stations was provided with its own oil pump. The former station is equipped with one 8,000, one 12,000, and one 14,000 gpm horizontal pump. The latter station contains two 3,000 and one 7,000 gpm pump. The Jones Falls pumping station is also provided with three horizontal centrifugal pumps, the largest of which has a capacity of 8,500 gpm and is equipped with an oil pump. All of the pumps discussed are horizontal centrifugal units with single-suction enclosed impellers. The suction inlet of each impeller was provided with a removable flat wearing ring. Adjacent to this wearing ring another one-piece wearing ring was fitted into the suction eye of each pump casing. The wearing

TABLE 1.

Effect of Adding Oil between Wearing Rings of Centrifugal Pumps

Test	Method of oil application	Pump characteristics			Test period		Time elapsed	Sewage pumped	Wearing ring clearance			
		Capacity	Total dynamic head	Speed	Beginning of test	End of test			Beginning of test	End of test	Amount of wear	Wear per billion gal pumped
		gpm	ft	rpm			years	mil gal	in.	in.	in.	in.
1	Oil not used				Jan 15, '51	Mar 7, '58	7.14	6,760	0.015[1]	0.276	0.261	0.039
2	Gear pump				Nov 28, '59	Aug 15, '60	1.71	1,736	0.015	0.016	0.001	0.001
3	Rotary displacement pump	3,000	36	425	Apr 24, '58	Dec 28, '58	0.65	669	0.037	0.038	0.001	0.001
4	Gear pump				Dec 28, '58	July 28, '60	1.57	1,762	0.038	0.042	0.004	0.002
5	Oil not used	8,500	92.2	508-632	Apr 18, '55	May 27, '58	3.10	4,987	0.015[1]	0.162	0.147	0.029
6	Gear pump				June 17, '58	Aug 4, '60	2.13	5,466	0.015	0.020	0.005	0.001
7	Oil not used	8,000	106	706	Mar 12, '56	Feb 12, '59	2.92	4,225	0.015	0.188	0.044	0.001
8	Gear pump				Mar 11, '59	Aug 8, '60	1.41	3,469	0.015	0.020	0.203	0.005

1. Estimated

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rings were originally made of bronze, containing 88 per cent copper, 8 per cent tin and 4 per cent zinc. After the clearance between the rings became excessive due to erosion, they were built up to their original thickness by the application of stainless steel, which had a Brinell hardness of 437. The speeds of the pumps, Table 1, varied from 425 to 706 rpm. All of the pumps operate under a suction lift. The sewage flow to each pumping station averages about 6 to 8 mgd and the quantity of oil used at each station varies from 30 to 40 gallons a week. The quantity of oil added to the sewage flowing to the two sewage-treatment plants which serve the city is very much less than 1 mg/l.

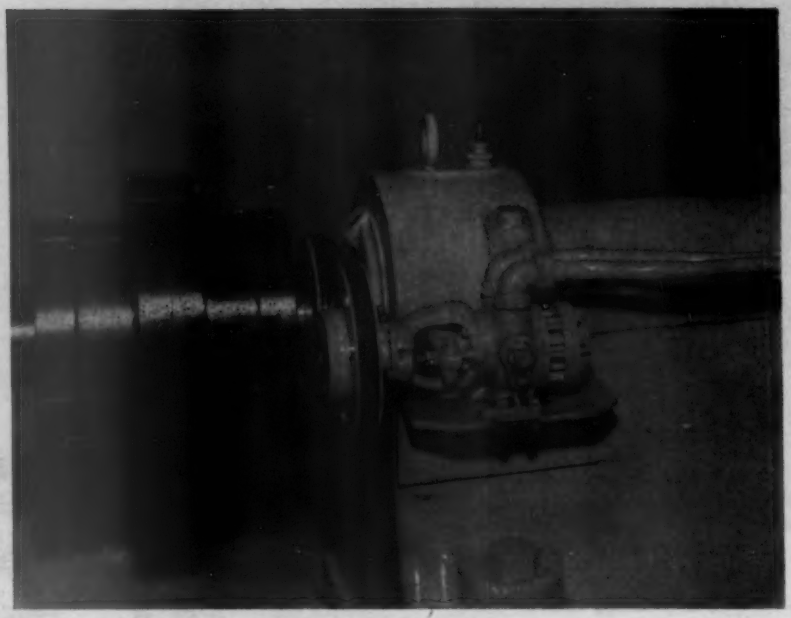


Fig. 3. Gear type pump used to pump oil to wearing rings at the Brooklyn Sewage Pumping Station.

Results

Eight tests were made over a period of 9¾ years at the Brooklyn, the Jones Falls and the Dundalk sewage pumping stations. Four tests were conducted at the Brooklyn station, two at the Jones Falls station and two at the Dundalk station. Tests were made using two pumps at the Brooklyn station and one pump at each of the other two stations. At each of the three stations one test was made to determine the extent to which the wearing rings were eroded when oil was not used, and five tests when oil was used. Table 1 gives the duration of each test, the quantity of sewage pumped during each test and the extent to which the wearing rings eroded.

Brooklyn Sewage Pumping Station

At the Brooklyn sewage pumping station the first test lasted from January 15, 1951, to March 7, 1958, when no lubrication was used. During this period of 7.14 years, 6,760 mil gal of sewage was pumped by one of the 3,000 gpm units, and the clearance between the wearing rings increased from 0.015 to 0.276 in. The rings wore at the rate of 0.039 in. per billion gallons of sewage pumped. The second test period, when oil was used, lasted for 1.71 years during which time 1,736 mil gal of sewage was pumped and the clearance between the wearing rings increased from 0.015 to 0.016 in. The wearing rings wore a negligible amount during this test. The third test using the second 3,000 gpm pump, lasted for 0.65 year from April 24 to December 28, 1958, during which time the rings wore at the rate of 0.001 in. per billion gallons of sewage pumped. At the end of Test 3, the use of a rotary-type displacement oil pump was discontinued and was replaced by a gear pump. Test 4 lasted for 1.57 years from December 28, 1958, to July 28, 1960, during which time 1,762 mil gal of sewage was pumped and the wearing rings wore at the rate of 0.002 in. per billion gallons of sewage pumped.

Jones Falls Sewage Pumping Station

The conditions at the Jones Falls sewage pumping station differ from those at the Brooklyn station in that the rate of discharge from the pump at the former station was more than twice that at the latter station. Furthermore, the total dynamic head was 92.2 ft as compared with 36 ft at the Brooklyn station. During the 3.10-year period from April 18, 1955, to May 27, 1958, when 4,987 mil gal of sewage was pumped and lubricating oil was not used, the clearance between the wearing rings increased from 0.015 to 0.162 in. or 0.147 in. The wear per billion gallons of sewage pumped was 0.029 in. The wearing rings were made of government bronze that had been subjected to considerable wear but which had been restored to their original dimensions by the application of stainless steel. The foregoing rate of wear to the wearing rings was considerably less than at the other two pumping stations when bronze pump rings were used and oil was not applied. The reason for there being less wear at the Jones Falls station was that the stainless steel rings were much harder than the bronze rings.

From June 17, 1958, to August 4, 1960, oil was applied to the wearing rings by means of a gear-type pump. During this period 5,466 mil gal of sewage was pumped and the clearance between the wearing rings increased from 0.015 to 0.020 in. The wear amounted to 0.001 in. per billion gallons of sewage pumped.

Dundalk Sewage Pumping Station

The experience at the Dundalk pumping station was similar to that at the other two stations. At this station observations were made using an 8,000 gpm centrifugal pump which operated against a total dynamic head of 106 ft. The pump was operated first for 2.92 years during which time no lubricant was used. During this period the clearance between the wearing rings, which were made of bronze, increased from 0.015 to 0.203 in. at a rate of 0.044 in. per billion gallons of sewage pumped. The rings were then metalized with stainless steel to restore the clear-

ance to 0.015 in. The pump was then operated for 1.41 years during which time oil was applied to the rings and 3,469 mil gal of sewage was pumped. The clearance between the rings increased from 0.015 to 0.020 in. or at the rate of 0.001 in. per billion gallons of sewage pumped.

Discussion and Conclusions

The observations made at the three pumping stations, which are equipped with centrifugal pumps, ranging in capacity from 3,000 to 8,500 gpm and which operate at speeds varying from 425 to 706 rpm indicated that the clearance between the wearing rings increased at the rate of 0.029 to 0.044 in. per bil gal of sewage pumped when lubricant was not added to the wearing rings. When lubricating oil was used the clearance between the wearing rings increased at the rate of approximately 0.001 to 0.002 in. per bil gal of sewage pumped. It is apparent that the use of spent lubricating oil has greatly reduced the wear of the wearing rings. The ultimate result has been that the cost of replacing worn out wearing rings or metalizing them to restore their original clearance has been considerably reduced and the efficiency of the pumps has been increased since less sewage flows between the wearing rings from the high to the low pressure side the pump impellers. This improvement in operation was accomplished at a minimum cost. Providing the Brooklyn pumping station, which has three centrifugal sewage pumps, with oil pumps, an oil storage tank, piping, etc., cost approximately $500. The cost of the power to operate the oil pumps is negligible, and the spent oil that is used is obtained gratis.

What one suburban water district is doing about . . .

Construction *of New Water Supply*

by GEORGE H. STRAUB, Superintendent, Westchester Joint Water Works No. 1, Mamaroneck, New York

EDITOR'S NOTE: This article describes what one suburban water district in the fast growing New York metropolitan area is doing to keep pace with the rapidly increasing demand for more and more water, and how it overcame the construction problems involved in a high-cost, sensitive residential area.

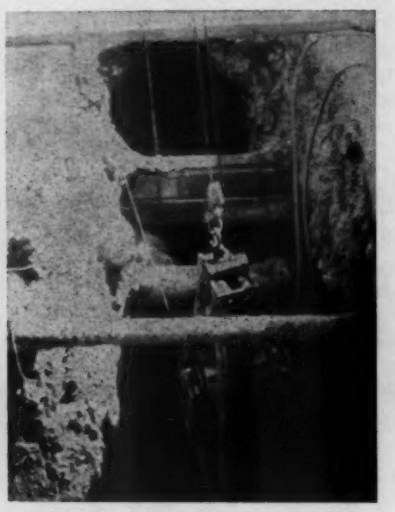
■ THE NEED for an additional supply of water to the Westchester Joint Water Works system had been recognized from the time of its organization as a union water district in 1927. At that time it relied for supply on a new filtration plant that purified the waters of the Mamaroneck River, a small stream flowing through the southeastern part of suburban Westchester County, N. Y. Although the plant was designed for 5 mgd, the flow in the stream was sometimes as low as 1 mgd and had to be supplemented by a siphon which pumped water from New York City's Kensico Reservoir.

In 1934, a pumping station was constructed on Kensico Reservoir to supplant the inefficient siphon. This gave a reliable yield of 7.5 mgd backed up by the impounded supply of 38 billion gallons.

The growth of Mamaroneck Village, the Town of Mamaroneck, and Harrison Town, the constituent municipalities of the Joint Water Works, and the fringe areas, supplied in Rye and New Rochelle, made it impossible

STEEL FORMS in place for walls of 24-in. Venturi chamber measuring water drawn from Delaware Aqueduct. Old 48-in. New York City Bronx River pipeline in background.

ENTRANCE to 60-in. tunnel with multiplate lining under Bronx River Parkway. Pre-assembled 30-in. pipe is ready to be slid into tunnel without interrupting heavy traffic.



CROWDED conditions under White Plains Rd., Eastchester, showing water and gas mains and telephone ducts. Men in background are hand tunnelling under concrete roadway.

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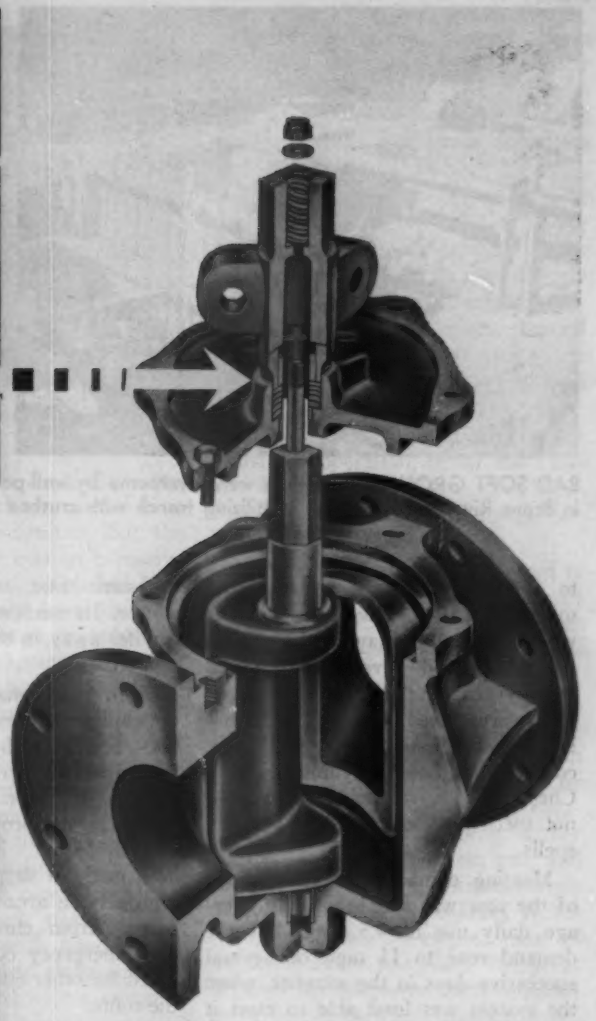
WITHOUT REMOVING PLUG FROM VALVE!!!



One major reason why **DeZurik Eccentric-Action Valves** are preferred in so many sewage services is their self-adjusting, leak-free stem seal. Multiple "chevron" packing is held under constant spring pressure, maintaining 100% sealing efficiency without the slightest leakage and without maintenance during long usage. The packing rarely requires changing, but when it does **YOU CAN CHANGE IT QUICKLY, EASILY,** at reasonably low pressures, **WITH THE VALVE STAYING RIGHT IN SERVICE.** You need not close down or drain the line.

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Easy, smooth operation

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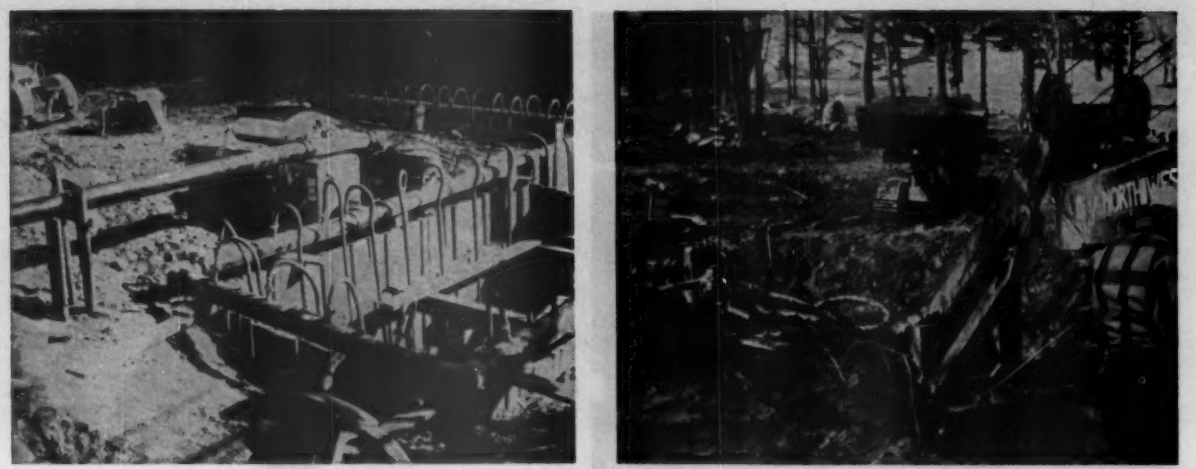


BAD SOFT GROUND conditions were overcome by well-pointing (left) at entrance to tunnel under railroad embankment in Bronx River valley and by stabilizing trench with crushed stone (right) in bog.

to meet demands in the summer months of 1947. Severe restrictions were invoked on lawn and garden sprinkling, and have been repeated every year from then until 1958. Even in its severe need, the district also felt impelled to assist the neighboring communities of Larchmont, Port Chester, and Silver Lake, which could not meet peak demands in hot dry spells.

Meeting demands for ten months of the year was simple with an average daily use of 4.5 mgd, but the demand rose to 11 mgd on several successive days in the summer, when the system was least able to meet it with the tiny 50 million gallon Mamaroneck Reservoir depleted and river flow at a minimum.

The unusual character of the district is that it supplies 10,000 accounts, most of which are high-class suburban residences with extensive lawns and expensive landscaping, which the homeowners were resolved to save even under drought conditions. In addition there are six exclusive golf clubs (one with 45 holes), which must be kept green. In other areas, wells are used by such country clubs; in our area, wells are almost non-existent because of the solid bed rock just under the surface everywhere.

Plan of Action

In 1954, consulting engineers were engaged to survey possible sources of supply. The completion of New York City's Delaware Aqueduct and its feeder system of reservoirs at about the same time, suggested a feasible source. Its nearest shaft was No. 22, 6 miles away in the northeast section of Yonkers.

With great reluctance—considering the capital cost, estimated at $1,300,000—but driven by dire necessity, the municipalities agreed to finance the venture in 1956. They have been joined in the project by the Village of Larchmont. Provision has also been made to supply a portion of the high service area of Yonkers, which suffers from chronic low pressure, and emergency connections are provided for other cities and towns along the route.

Construction Details

Construction was started in December 1957. The pipeline furnishes, conservatively, 16 mgd by gravity to the center of the feeder system in Mamaroneck. Another 4 mgd can be added by pumping. Adding the rated capacity of 5 mgd for the Mamaroneck Plant, and 7.5 mgd for the Rye Lake (Kensico) Plant, gives a potential of 32.5 mgd, which gives entirely adequate water for all the needs of these communities for the foreseeable future.

The pipeline consists of prestressed reinforced concrete cylinder pipe of various weights designed to meet the stresses due to the change in head as the pipe goes up hill and down dale in crossing Westchester County from west to east. The rock ridges of the County run north and south. There are many pipelines running in that

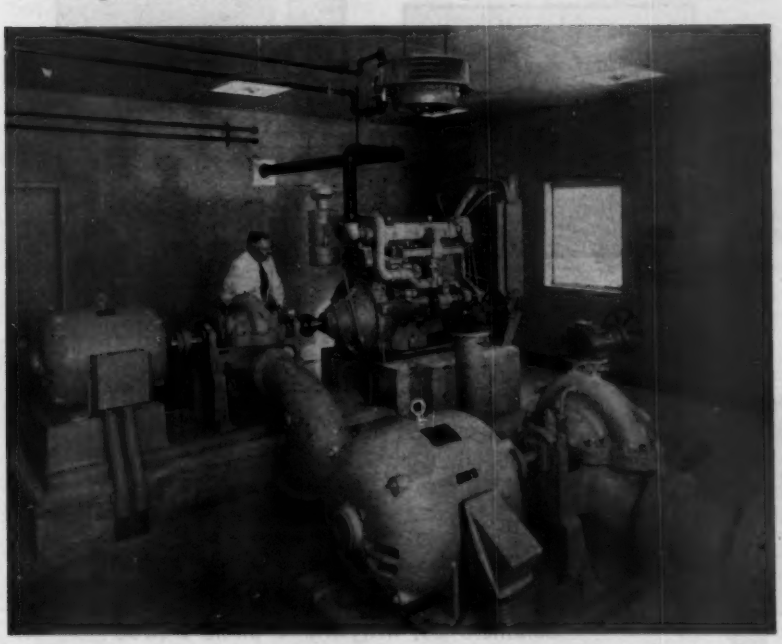
BLASTING of difficult excavation in solid rock in easement next to new residence at Hutchinson River, Eastchester, required extreme care to prevent damage.

CHEMICAL FEED and pumping station in Town of Mamaroneck just over Larchmont line.

direction, but this is the first water main to cross the ridges at right angles. This necessitated the installation of air release valves at a number of points to prevent air binding and consequent reduction in volume of flow.

Shaft 22 of the Delaware Aqueduct is a deep shaft with two riser pipes to the surface surmounted by headers to provide four 36-in. bronze gate valves for connections. The new pipeline originates at this point. A 24-in. Venturi meter has been installed just east of the shaft with a remote recording device located within the shaft chamber. This meter registers flow from 130,000 gpd to the maximum capacity of the new 30-in. pipeline, which runs 5 miles to the Town of Mamaroneck.

Crossing under the old 48-in. Bronx River pipeline of New York City and a maze of other utilities at the same point presented difficulties, but the first major obstacle was an extensive swamp in Crestwood which had been filled with tunnel spoil from the excavation of the Delaware Aqueduct. A 36-in. sewer line supported on timber piles also crosses this area. Shifting of the unstable ground had broken this sewer and it was leaking. The combination of ground water and sewage forced the contractors to use two 6-in. and a 4-in. pump with long discharge hoses during the time of excavation for the new main, which has a 4-ft cover over the pipe throughout its length. The trench was stabilized through this area with hundreds of cubic yards of crushed stone and the pipe was surrounded with a concrete envelope for several hundred feet.



INTERIOR of Larchmont station, showing pumps for intermediate service area.

From this point east, the trench was excavated in solid rock with only minor exceptions. The total rock excavated amounted to 22,000 cubic yards, whereas earth excavation was only 4,500 cubic yards.

Leaving Yonkers, the main was tunneled underneath the Bronx River Parkway in order to maintain traffic on this important artery, then directly into the bed of the Bronx River. Emerging from the river, several hundred feet of well-pointing were required to handle the heavy ground water to keep the trench dry.

We then encountered the second tunnelling operation, under the Harlem Division of the New York Central Railroad, which is on a high embankment at this point.

Well-pointing also was required to handle ground water in the valley of a small stream in crossing the Leewood Golf Course. Then back to rock again.

Crossing under the White Plains Road in Eastchester presented the most difficult traffic control problem of the entire job. This was solved by proceeding partially in open excavation, partially by tunnelling. Other utilities—telephone, electric, gas, and several large water transmission mains of the New Rochelle Water Company— had pre-empted most of the space under this road. The great depth of the telephone ducts required going deeper than had been expected.

Through the Vernon Hills Golf Course it was necessary to fell many trees of large diameter. We also encountered a bog, which required floating the backhoe on pontoons.

On either side of the Hutchinson River, a small stream, we line-holed the rock banks; subsequently, reduced charges with delay fuses were used as a way was blasted close to fine residences through easements in private property.

In New Rochelle, city streets were followed for over a mile before tunnelling under the Hutchinson River Parkway, then following and ultimately crossed the Sheldrake River.

Approaching the Sheldrake Reservoir of the Village of Larchmont, the pipe was laid across a shallow arm of the reservoir and then filled it in, to avoid rock cliffs on the edge.

Chemical Feed Station

At the base of the Sheldrake dam

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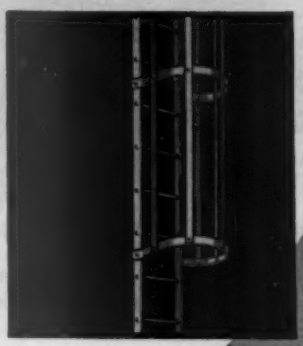

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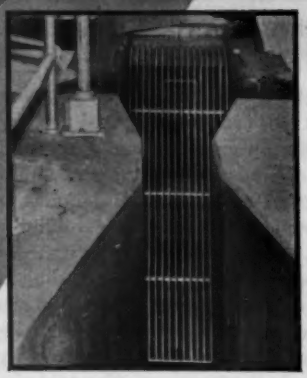

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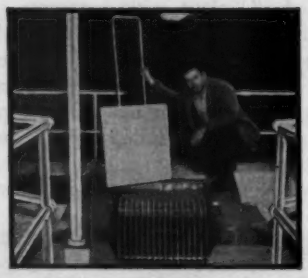

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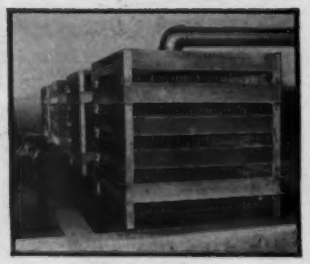

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PARALLEL MAINS for low service area (30 in.) and intermediate service area (16 in.) were laid (left) in rock cut in Bonnie Briar golf course and under bed of Sheldrake River beneath State Highway 125. Stream is dammed and diverted around excavation.

the main finally entered our own water district, where a chemical feed and pumping station was erected.

The new station receives and measures the gravity flow of water through a Gentile tube. The differential in pressure in this tube also energizes and controls the feeding of chemicals through a meter, which paces the chemical feeders according to flow. Sodium silicofluoride is fed by a dry chemical feeder and the solution is pumped into the water. The water as received contains a slight chlorine residual provided by New York City, but more is added as a safety factor. The third chemical added is sodium hexametaphosphate to minimize discolored water troubles.

This station supplies the low service area, which uses 75 percent of the water, but pumps having 6-mgd capacity and auxiliary gasoline engines are provided to raise the head for supplying the intermediate service area at higher elevations. The latter area, representing 20 percent of the use, is at present supplied by the Mamaroneck Plant. The remaining 5 percent is pumped to the high service area by the Rye Lake Plant.

Consequently, two mains leave the plant—a 30-in. one for the low service area; a 16-in. one for the intermediate service area, which immediately adjoins the station.

Both mains cross below the lower Sheldrake dam and then are laid beneath the stream bed to cross beneath the bridge which carries State Highway 125 over it.

Distribution

Just beyond, in the Bonnie Briar Golf Course, the 16-in. main connects with the local intermediate transmission and distribution mains.

The 30-in. main makes its first feeder connection here and continues as a 24-in. line into the center of Mamaroneck, making three further feeder connections on the way.

Another feature of the system is that butterfly valves are used throughout on the main lines (30, 24, and 16-in.) These valves are located at least every mile, and at intermediate connections.

Two connections are provided for the Village of Larchmont, an independent system. One of these is before the station, the other after it, so that they can take either treated or untreated water.

The City of Yonkers connection, being located near the origin of the line, provides untreated water. The City plans to construct its own treatment facilities.

Easement Problems

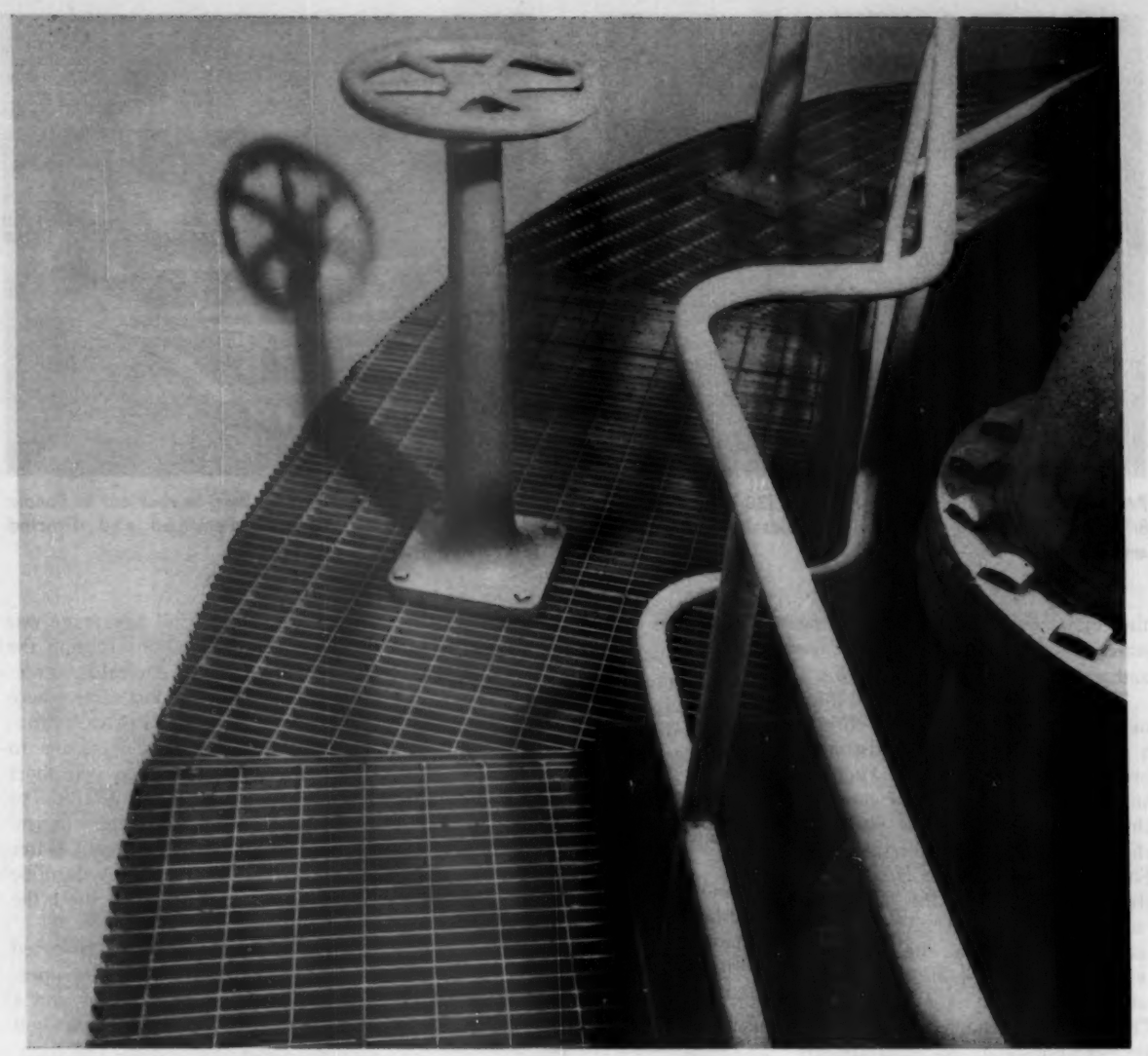
There were a number of difficulties in the acquisition of easements, but most of the route required no expenditure for that purpose as it followed city streets in Yonkers, Eastchester, New Rochelle, Larchmont, and Mamaroneck; reservoir property; and a stretch of over ½ mile along Westchester County lands originally acquired for a parkway that has never been constructed. Full advantage was taken of vacant land in crossing the three golf courses. Amicable agreements were made in most cases where easements were used in private property. However, it was necessary to resort to condemnation in two short stretches (totaling only 300 ft) to avoid protracted negotiations unnecessarily holding up this urgent water supply for 46,000 people. A deadline had been set to be able to meet the heavy summer load in 1959.

In summary, the main was tunneled under one railroad and two superhighways, crossed six streams and a reservoir, two swamps, three golf courses, numerous streets and highways, and had to be blasted most of the way through granite crossing Westchester County.

Consulting engineers laid out the work of the five contractors, who were supervised by the district's own staff.

Primarily because of the excessive rock, costs exceeded the original estimates by about $400,000, with a final cost of $1,700,000.

Appropriate ceremonies were held when water first flowed through the facilities on May 24, 1959, just in time to avoid the usual summer restrictions. Now the people served can enjoy unrestricted use for their lawns, gardens, air-conditioning, and swimming pools, besides the normal sanitary uses. That they are taking advantage of it is indicated by the average use of 125 gallons per capita in 1959, as opposed to 102 gallons in 1957.



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by F. D. LYON,
Watsonville, Calif.

EDITOR'S NOTE: This article reports briefly on how a 3,850 ft sewer outfall was laid on the floor of Santa Cruz Bay. The steel pipe was was joined, coated and inspected on shore, then pulled out to sea by winches. Usually an expensive and difficult operation, the actual pulling of the nearly three-quarters of a mile of pipe took 32 hours. The cost of the outfall installation was about $460,000.

■ THE FREEDOM SANITATION DISTRICT of Santa Cruz County, Calif. has just completed a new ocean outfall sewer extending 3,850 ft into Santa Cruz Bay. This was the first fixed declivity and heaviest outfall pipe pulling project of record on the Pacific Coast. The submerged outfall will receive primary effluent from a new sewage treatment plant on the outskirts of Watsonville and the industrial wastes from the area. The industrial effluent pipe line of 22 in. diameter and the 42 in. sanitary effluent pipe line run parallel three miles to a beach surge chamber, where they combine to enter the new ocean outfall line.

The ½ in. wall thickness, 39 in. diameter steel pipe was hauled to the beach in 30 ft. lengths. The outfall piping was welded into 480 ft lengths on the beach and each weld was inspected using x-ray techniques. These lengths were laid parallel to the pulling line and each was equipped with end bolting flanges. On the pipe interior, a 1 in. coating of spun mortar was applied to 4 x 4 wire mesh. This cured for 7 days. On the pipe exterior ¼ in. steel wire was wound at 1 in. intervals, covered by a 3 x 4 wire mesh, then a ½ in. coating of fiber glass and coal tar applied. Over this, a 3 in. Gunite mortar coat completed the exterior protection, giving a total pipe diameter of 42 inches.

Tractors pulled the 480 ft lengths to the pulling line on triple rubber-tired rollers set in cradles which were spaced at 24 ft intervals. These cradles were designed to support 50 degrees of the pipe's lowest periphery. Hydraulic jacks were used to place the pipe on the cradles and to obtain proper roller seating. On the 1 per cent slope, a tractor hold-back winch released the pipe lengths which traveled on the rollers and permitted end flange bolting of fabricated lengths. The bolted flanges received a coal tar application before placing a sheet steel recessed clamp, which was grouted to refusal. The action of the sea water is expected to disintegrate the steel clamp, leaving the tar and grout to satisfactorily seal the bolted flanges.

At the sea end of the joined pipe, a sealed pulling head was attached by cables leading over a pulling buoy to a barge 200 yards offshore. The barge was equipped with diesel motor winches. Because of the heavy fog, it was impossible to see the pull-

GROUTING SLEEVE being fitted on the first section (lef t) prior to flange bolting (right). The sleeve will then be placed to cover the joint and cement grouted.

ing barge or the hold-back winch from the central pull controlling point, so a radio-phone was utilized. The pulling head end of the pipe was mounted and the pipe was centered between driven piles on the beach. The final 100 yards to water was over sandbags. The barge winches made 2 ft closely inspected pulls as roller assemblies were moved in to insure level at low spots and bulldozers cleared out intruding sand. Though it had been estimated at 48 hours, with the thorough preparation and co-ordination, the pull was actually completed in 32 hours.

During the entire pulling operation, divers continually inspected the pipe for rotation, and after the pipe was attached to the surge chamber, they removed the end pulling head and opened the end air valve, dropping the pipe down 60 feet to the ocean floor. Though the pipe weight was 856 pounds per foot on shore, in the water with the buoying entrained air it weighed only 10 pounds per foot.

To supplement the end outfall capacity of the pipe, there are twelve staggered 8 in. diffusers which can be opened if required. With the installation of this new outfall sewer, the two former 16 in., 1750 ft outfalls will be abandoned.

The new primary sewage treatment plant provides for both pre and post-chlorination. The sewage flow, half sanitary and half industrial wastes, will require the outfall to handle a combined flow of 6.7 mgd. In treating the sanitary wastes, a BOD of 6,000 pounds daily will drop to 4,500 pounds daily, a decrease of 25%, with the suspended solids dropping from 6,000 pounds daily to 2,700 pounds daily, a decrease of 55%; in the industrial, BOD will decrease 15% from 2,400 pounds daily to 2,040 pounds daily; the primary consideration, the industrial suspended solids, dropping 60% from 2,400 pounds daily to 840 pounds daily.

The new sewage treatment plant is a joint project of the City of Watsonville and the Freedom Sanitation District of Santa Cruz County. It is financed by revenue bonds, and will probably be assisted by increased sewer service charges. The new outfall was a separate obligation of the District.

FIRST LENGTH of outfall in place between aligning piles. The pulling head is attached ready for the pull.

FIRST SECTION of the outfall shows diffusers. The pulling buoy is shown at the top right with pulling lines extending out to the winching barge located a quarter of a mile out in the fog.

Bascule Gates for increasing reservoir capacity

by G. E. THOMAS,
Project Engineer
Metcalf & Eddy, Engineers
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RESUME: The capacity of a reservoir can be increased in many ways. Of these, the more popular methods are raising the spillway crest, flashboards, by excavating in the reservoir, and by installing radial or bascule gates. With the exception of the two types of gates, the other methods are quite costly either for first cost or maintenance.

Bascule gates are usually the most desirable of the types of gates since they do not require an overhead structure. Further, they provide automatic opening and closing controlled by the water level in the reservoir. Various installations of this type gate, which is basically a hinged steel flash board, have shown it to be quite useful.

■ WITH THE OVERWHELMING increase in water consumption over the past twenty years, together with the frequent dry periods encountered, increasing water storage capacities has become a subject of universal consideration. For this reason increasing critical attention is being given to considerations of water reservoirs and, in particular, to the problem of how an existing reservoir can be modified to increase its storage capacity.

In general, increasing the storage capabilities of existing reservoirs can be approached in a number of ways. One method, gaining considerable interest of late, is the use of bascule gates. In order to appreciate the advantages of this unit, it will be necessary to briefly review the other methods in current use.

Raising Spillway Crest

A permanent increase can be obtained by raising the elevation of the spillway crest. Depending upon the adequacy of the original flow capacity of the spillway, it is generally necessary to increase the height of the spillway abutments and embankment sections of an earth dam and the non-overflow sections of a concrete dam in order to maintain the required spillway capacity and freeboard. The costs associated with this method of modification are usually considerable, because of the sizeable quantities of concrete required to gain additional height and to preserve the symmetry of the spillway, in addition to the costs of hauling and placing additional earth on the embankment under restricted space conditions.

Flashboards

A common method of providing a temporary increase in reservoir storage capacity is the use of flashboards. These are generally installed after the flood season and remain in place until removal just before the start of the next seasonal flood period.

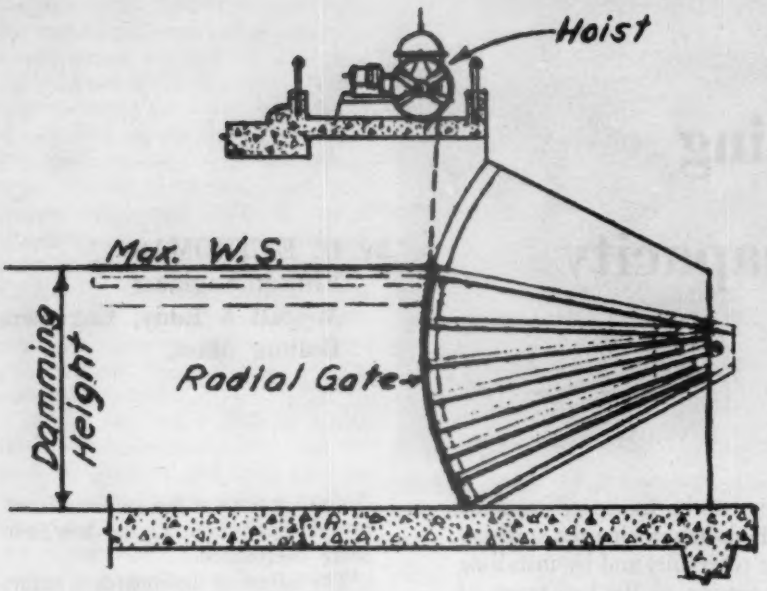
Flashboards are usually attached by wire to vertical metal pipes or pins secured to the crest of the spillway. These pipe or pin supports are designed to fail under a predetermined head of water flowing over the top of the boards. With the collapse of the boards under such conditions the design capacity of the spillway is restored, thus preventing the dam from being overtopped.

The failure of flashboards is naturally quite sudden, and the resulting surge or wave of water which develops downstream can be damaging to structures in its path. At the same time, the gain in water storage from the installation is totally lost. The installation must be replaced before storage can once again start building up.

Flashboards involve a relatively low initial cost. The maintenance work required, however, can be appreciable. For one thing, there can be considerable difficulty in minimizing leakage. Untimely failure of flashboards can also occur due to an unexpected flash flood. When failure does occur, whether expected or otherwise, most of the boards will be swept downstream while others will be damaged considerably. At the same time, many of the supports will be bent or otherwise damaged and will also require replacement.

When replacing a flashboard installation that has failed, there is the chance that the new or repaired supports will be inconsistent with the design strength of the initial installation. Such a condition can result in the flashboards failing prematurely or not failing at all. In the latter case, the required waterway will not be available and the dam may be overtopped with considerable damage or possible failure.

Two other types of board installations are the hinged type and the fixed stop-log type. The first consists of panels hinged at the crest of the spillway. The panels are supported on the downstream side by wooden



A TYPICAL RADIAL gate installation.

struts designed to fail at a predetermined head of water. Although the boards are not lost with this type of installation, the other disadvantages still prevail. A stop-log installation consists of boards secured in fixed vertical guides. Since the boards must be removed manually, it is essential that they be kept free working and that operating personnel be extremely vigilant of water level.

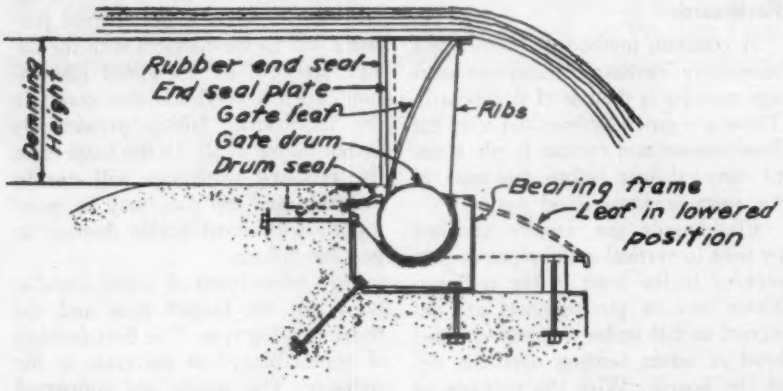
Because of the number of variables involved, some state regulatory agencies will not permit flashboard installations except under carefully supervised conditions.

Excavation in Reservoir

In some instances reservoir storage capacity can be increased by excavation in the reservoir area. With this method, however, there exists the possible danger of increasing seepage around the rim of the reservoir or under the dam itself, assuming there is no complete cutoff under the structure. The cost of this operation can be very high.

Radial Gates

Another method of increasing reservoir storage is with the use of crest gates. One type of crest gate is the radial or Taintor gate, which rotates about a trunion on the crest of the spillway. The gate is operated by an overhead hoisting device connected by cable or chain to its two lower corners. The thrust from the water pressure is carried by the trunion bearing which offers little resistance to the operation of the gate. The operating load consists of the dead weight of the gate, ice load, friction, and the torsional resistance of the trunion bearings. The primary feature of these gates is their simplicity of operation. It is generally necessary to construct an overhead operating structure the entire length of the spillway. In some instances the position of an existing bridge over the spillway prevents use of this type of gate installation.



ELEVATION VIEW of a bascule gate installation.

Bascule Gates

The bascule gate is a particular type of crest gate which possesses the advantageous features of the radial type crest gate plus the feature of gradual automatic raising and lowering. Although capable of manual operation when desired, bascule gates normally function automatically. The automatic opening and closing of the gates is controlled by predetermined maximum and minimum reservoir levels. It is this automatic operation without the loss of water storage which makes the bascule gate so desirable.

Basically, the bascule gate is a hinged flashboard. Constructed of steel, it consists of a contoured gate leaf attached to a torsion cylinder which rotates on a series of bearings secured to the crest of the dam. The ends of the torsion cylinder are set in the spillway abutments. A lever assembly, attached to one end or both ends of the torsion cylinder, and the operating mechanisms are housed within the spillway abutments. Rubber sealing strips mounted on the piers and on the crest of the spillway complete the closure of the gate leaf when it is in the vertical position, preventing water seepage around or under the gate. A series of bearing frames, mounted on the spillway, support the torsion cylinder.

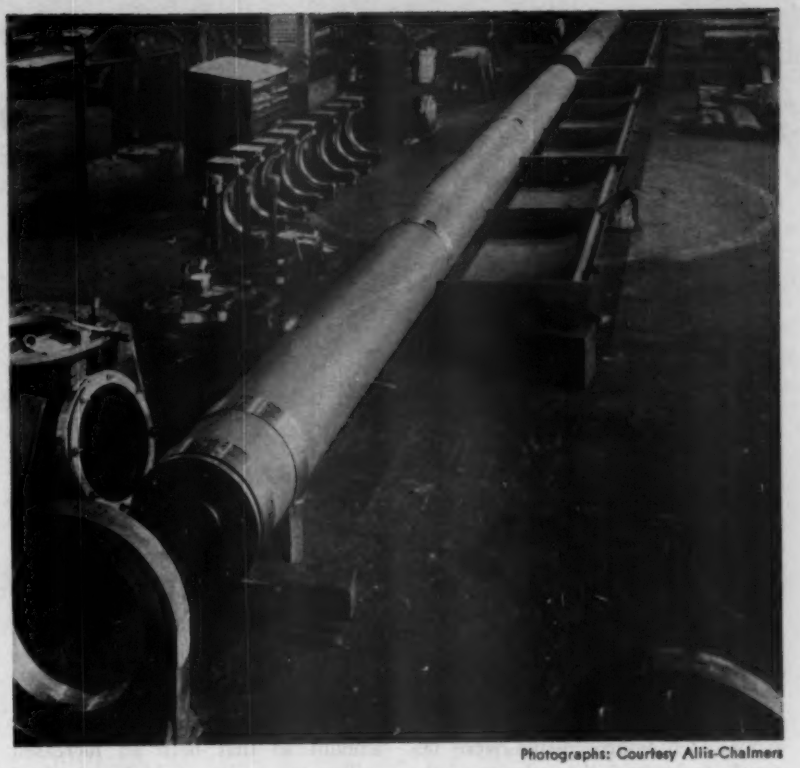
To mount the bascule gate, a section of the dam crest is cut away and the bearing assemblies are secured to the dam at equal intervals. For operation in the winter months, electric heaters are installed at the seals, and heating of the torsion cylinder is also provided to prevent the formation of ice from interfering with the operation of the gate.

The bascule gates are operated hydraulically with an oil pressure of 300 to 400 psi. The automatic control feature is accomplished by means of a float valve and well which duplicates the level of the reservoir. A relief valve is provided in the oil line to allow for excessive pressure being exerted on the gate by ice or debris

when the gate is in a vertical position. When such pressure are exerted on the gate, it will lower automatically to permit the debris or ice to pass over the crest. This relief valve also acts as a safety device in that it can be operated to lower the gate under flood conditions should operating valves become inoperable or the oil lines become plugged.

Normal raising or lowering of the gates is governed by a throttling valve, the rate of speed being about 1 ft per minute. A compensating mechanism is provided to prevent overtravel.

Bascule gates are available in single span sizes up to 10 ft in height and 100 ft in length. They are constructed in sections to facilitate handling, field erection, and assembly. For spillway spans in excess of 100 ft, the gates are installed in sections. For a bascule gate installation having two separate spans, separate operating mechanisms are provided at either end of the dam. With a multispan installation, there is the advantage of having one gate set for automatic regulation of minor variations in reservoir level, and the others set for automatic operation to handle the larger variations in reservoir level.



Photographs: Courtesy Allis-Chalmers

SHOP VIEW of gate assembly showing fabricated torque tube, gate leaf, and mounting bearings.

Installations

A typical installation of bascule gates was recently designed and supervised by the author's firm, for the North Fork Reservoir Dam of the Johnstown Water Company in Pennsylvania. The gates were manufactured by Allis-Chalmers Manufacturing Company of York, Pennsylvania. The dam had an ogee type spillway which was divided into three bays by two concrete bridge piers which supported an overhead concrete service bridge.

The Johnstown Water Company was faced with the urgent problem of increasing the storage capacity of the reservoir. Raising the crest of the concrete spillway and embankment of this earth dam was not feasible. State regulation prohibited a flashboard installation, and radial crest gates could not be employed because of the overhead bridge. The State also required that the original spillway capacity should not be reduced. Bascule gates were ideally suited to this set of conditions.

To permit installation of the bascule gate, a section of the concrete spillway was removed. Because of the relatively short span between bridge piers, one continuous torsion cylinder was used. Holes were drilled through the two division piers and one dam abutment. Holes and slots were made in the concrete spillway for the placement of anchor straps and bolts. A concrete apron was placed over the horizontal surface of the recessed section of the spillway. The seal plate, sill beam, and anchor straps were then grouted into place in the vertical surface of the recessed spillway section. Three bronze-lined saddle bearings were installed on the concrete apron in each bay to support the torsion cylinder.

The end seals of the gates at the piers and abutments consist of steel plates set out from the supports a distance of 6 in., with nonshrink grout used to fill the void between the steel plate and the supports. The actual water seal is accomplished by a length of rubber tubing attached to the steel plate.

An underground control room was constructed in the enbankment adjacent to the left abutment, this side of the dam being closest to the access road and power lines. The room is 10 ft wide, 14 ft long, and 12 ft high, with concrete floor, walls, and roof. Housed within the control room are the oil pumping unit, the hydraulic cylinder and operating lever, control panel, and float well. The float well consists of a 24 in. diameter Schedule 40 standpipe, with a 2 in. intake pipe leading from the reservoir just upstream of the spillway crest, and passing through the abutment wall to the float well. Electrical service is provided for operation of the oil pressure pump, lighting, and heating. A floor drain was included, discharging downstream into the spillway channel. The drain serves a dual purpose: it supplies air to the control room to replace that exhausted by the roof ventilator; and, with the onset of winter, the drain is used for the purpose of emptying the water from the float well. Use of the gates for the purpose of increasing storage was limited by State regulation to the period of April 15th through November 15th. For this reason, no heating provisions were included.

As a result of this 3 ft high Bascule gate installation, the 1100 million gallon reservoir storage capacity was increased by about 92 million gallons.

At York, Pa., bascule gates were found to be ideally suited to the spe-

A SET OF GATES in the process of installation.

cific needs of the York Water Company. Two improvements were desired: to increase the capacity of the existing spillway, and to increase the capacity of storage in the reservoir. The existence of a state highway bridge over the spillway was an extremely critical factor. It was not possible to raise the bridge a sufficient amount so that both an increased spillway capacity could be obtained and the crest of the spillway be raised for the purpose of increased storage. The solution was obtained by raising the bridge a sufficient amount above the existing spillway crest for the needed increase in spillway capacity; this with an installation of bascule gates which would provide the desired increase in storage capacity and at the same time not affect the required spillway capacity during the flood season of the year. These gates were 4 ft high and built in two 93 ft sections, individually controlled by separate operating mechanisms in either abutment. As a result of the gates, a 900 million gallon storage was increased at the York Water Company Reservoir by about 250 million gallons.

A BASCULE GATE in the lowered position.

The application of bascule gates on reclamation dams, water supply projects, and power dams is becoming quite popular. In addition to the Pennsylvania installations, they can be found at Athol, Mass.; at a dam performing flood control service in Orange, Mass.; near Boston, Mass. controlling the stream flows of the Neponset and Charles Rivers; and in use under severe winter conditions at a power dam in St. Albans, Vt. Each of these installations is an example that bascule gates are the answer to the perplexing problem of increasing reservoir storage under severely limiting conditions.

Considerations

In the design of a bascule gate installation, there are some basic considerations necessary. For one thing, there is the resulting stability of the dam and the degree to which it may or may not be affected by the increased head of water made possible by the gates. In some instances, this may be the deciding factor in determining the height of the gates to be installed and, in cases where the original spillway capacity must be maintained, it is essential to investigate the resulting coefficient of discharge of a proposed gate installation. The contour of the gate will be governed accordingly.

Research indicates that serious consideration should be given to . . .

Swimming Pool Disinfection with Iodine

by A. P. BLACK
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University of Florida
Gainesville, Fla.

Iodine As An Element

■ I_2 POSSESSES the highest atomic weight of the four halogens, is least soluble in water, is least hydrolyzed by it, has the lowest oxidation potential, and reacts more slowly with organic compounds by either addition or substitution.

These somewhat negative characteristics might at first sight appear to be limiting factors with respect to iodine's use for the disinfection of swimming pool water. Actually, however, just the reverse is the case because taken collectively they mean that low I_2 residuals should be more stable and, therefore, persist longer in the presence of organic or other oxidizable matter than any of the other halogens.

In evaluating the effectiveness of any agent for the disinfection of swimming pool water we must be familiar with all of the chemical reactions it is likely to undergo under actual conditions in use. For example, it has been shown that HOCl, formed by the reaction of Cl_2 with H_2O, is most effective and that chloramines, formed by the reaction of Cl_2 or HOCl with ammonia, and hypochlorite ion, formed in increasing amounts as pH increases, are much less effective. In the case of I_2 five different factors and four different substances must be considered.

The Chemistry of Iodine at Pool Residual Concentrations

Hydrolysis of I_2

$$I_2 + H_2O \rightleftarrows HIO + H^+ + I^- \quad (1)$$

$$\frac{[HIO]\,[H^+]\,[I^-]}{[I_2]} = K_a \quad (2)$$

$$K_a = 3 \times 10^{-13} \text{ at } 25°C.$$

Equation (1) shows the reaction of I_2 with H_2O to form hypoiodous acid, and the hydrolysis constant K_a is calculated from equation (2). Its value is 3×10^{-13} at 25°C. Using that value, Chang[1] has calculated the effect of pH on the reaction for total I_2 concentrations of from 0.5-50.0 ppm. Fig. 1 is taken from his paper and shows that, whereas at the higher I_2 concentrations, most of it is present as diatomic I_2, even at pH 8.0; at the residual concentrations encountered in swimming pool disinfection at pH 7.0, about one half is present as diatomic I_2 and one-half as colorless HIO. At pH 8.0 the values are 12 percent as I_2 and 88 percent as HIO. We, therefore, have not one but two active germicidal agents present in the pH range encountered in proper swimming pool operation.

Effect of pH on Forms of I_2

The second factor to be considered is the effect of pH on the conversion of hypoiodous acid, HIO, to hypoiodite ion, IO^-

$$HIO \rightleftarrows H^+ + IO^- \quad (3)$$

$$\frac{[H^+]\,[IO^-]}{[HIO]} = K_a = 4.5 \times 10^{-13} \quad (4)$$

$$[H^+] = K_a \frac{[HIO]}{[IO^-]} \quad (5)$$

$$\frac{[HIO]}{[IO]^-} = \frac{[H^+]}{K_a} \quad (6)$$

Now for pH 8.0

$$\frac{[HIO]}{[IO^-]} = \frac{1 \times 10^{-8}}{4.5 \times 10^{-13}} = 2.2 \times 10^4 \quad (7)$$

And for pH 9.0

$$\frac{[HIO]}{[IO^-]} = \frac{1 \times 10^{-9}}{4.5 \times 10^{-13}} = 2.2 \times 10^3 \quad (8)$$

Equation (3) is the reaction for the dissociation of the acid to hydrogen ion and hypoiodite ion and equation (4) is used to calculate the dissociation constant, K_a, which is 4.5×10^{-13}. In other words, HIO is only very slightly stronger than H_2O as an acid.

Equations (5) and (6) show that it is possible to calculate for any hydrogen ion concentration and pH value the ratio of the undissociated acid to hypoiodite ion. Equation (7) shows that at pH 8.0 this ratio is 2.2×10^4 and equation (8) shows that at pH 9.0 it is still 2.2×10^3.

We find, therefore, that at pH 8.0 there are 22,000 undissociated HIO molecules to each hypoiodite ion and at pH 9.0, which should never be reached in proper pool operation, there are still 2,200 undissociated HIO molecules to each hypoiodite ion.

It is of interest to compare the effect of the pH value on Cl_2 and I_2 residuals. Table 1, taken from the classical paper of Wattie and Butterfield[2], presents the data for Cl_2 and Table 2 for I_2.

The data show that whereas at pH 8.0, 78.5 per cent of a Cl_2 residual is present as relatively ineffective hypochlorite ion and only 21.5 per cent is present at HOCl at the same pH of 8.0, 88 per cent of the corresponding I_2 residual is present as HIO, 12 per cent as diatomic I_2, and only 0.005 per cent, or an unmeasurable trace, is present as hypoiodite ion.

These data have two very important practical implications to the use of I_2 for the disinfection of swimming pool water. First, if it can be demonstrated that HIO is an efficient bactericide in low residual concentrations, then higher pH values than have customarily been employed for swimming pool water become permissible. Second, if pool water is maintained at approximately pH 8.0, less than one-fifth of a total I_2 residual is present as colored diatomic I_2 and color formation in pool water is no longer a problem.

Formation of Tri-Iodide Ion, I_3^-

The third factor is the possibility of the formation of deeper colored and bactericidally inactive tri-iodide ion, I_3^-, in the presence of a large excess of KI. Chang[1] has investigated this point and Fig 2 is taken from his paper. Inspection of the curve shows that the formation of tri-iodide ion, I_3^-, will not be significant or even measurable at the concentrations of I_2 and KI which would be present in approved swimming pool practice.

Formation of Iodate

The fourth factor is the conversion of HIO to iodate at high pH values. The reaction is as follows.

$$3\,HIO + OH^- \rightleftarrows HIO_3 + 2\,H_2O + 2\,I^- \quad (9)$$

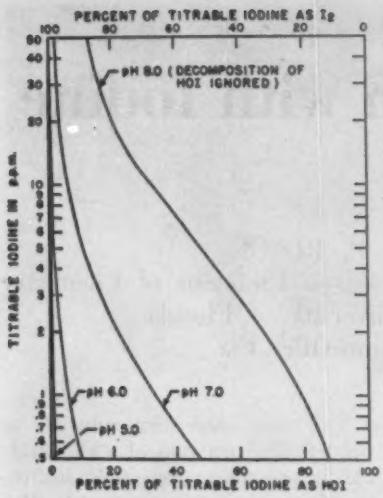
PERCENT OF TITRABLE IODINE AS I_2
pH 8.0 (DECOMPOSITION OF HOI IGNORED)
pH 6.0
pH 7.0
pH 5.0
TITRABLE IODINE IN p.p.m.
PERCENT OF TITRABLE IODINE AS HOI

FIG. 1. THE PERCENT of titrable iodine as I_2 and as HOI in aqueous solutions at 25°C.

In our work with Florida pools, we have not found iodate build-up to be an important factor.

No Reaction With Ammonia

The fifth factor to be considered is the question whether I_2 or HIO will combine with ammonia or ammonia derivatives in pool water to form iodoamines. While it is known that strong solutions of I_2 and ammonia will combine to form the very explosive compound, NI_3, it has been shown that there is no reaction in the concentrations which would be encountered in normal swimming pool operation. This fact constitutes another advantage resulting from the use of I_2 for the disinfection of swimming pool water.

Disinfecting Power of the Various Forms of Iodine

Research workers are not in complete agreement with respect to the disinfecting action of the various forms of I_2 but it is believed that the following statements correctly summarize the best present information.

Studies by Chambers, Kabler, Malaney and Bryant[4]; Chang and Morris[5]; Morris, Chang, Fair and Conant[6]; and Chang[1] have shown that elemental I_2 possesses excellent germicidal properties against all types of pathogenic organisms within a reasonable time at a concentration of a few parts per million.

Some years ago our Armed Services adopted iodine-releasing tablets in place of the Halazone, (chlorine), tablets for disinfection in the field of water in canteens, based on the finding that I_2 in drinkable dosages will kill amoebic cysts while chlorine will not. It also possesses excellent virucidal properties. Wyss and Strandskov[3], in an early paper which is frequently quoted, compared the bactericidal effects of I_2 and HIO. They prepared "pure" solutions of HIO by treating I_2 solutions with a suspension of HgO, shaking and filtering, which was stated to have removed free I_2, and made available a solution containing only HIO. They found that the bactericidal effect of "iodine free" (the quotes are my own) HIO solutions was only one-third to one-sixth that of an equivalent amount of free I_2.

On the other hand, Carroll, Iannarone and Stonehill[7] prepared solutions of HIO by adding either Cl_2 water or a solution of chloramine-T to a solution of potassium iodide and found that when such solutions are properly buffered there results within seconds a colorless solution of hypoiodous acid. Employing suspensions of *Micrococcus pyogenes* var. *aureus* ATCC 6538—P, and *Escherichia coli* ATCC 9367 as test organisms, they found hypoiodous acid to be roughly four to five times as effective as diatomic iodine vs. *M. pyogenes* and about three times as effective vs. *E. coli*.

Berg, Chang and Kabler, in a paper presented before the 1960 meeting of the American Society of Bacteriologists, stated that:

" . . . . . hypoiodous acid (HOI), which increases in concentration as the pH of the water increases, appears to be a more potent virucide than I_2. Preliminary data indicate that on a milligram per liter basis, HOI will destroy 99 per cent of Coxsackie A9 virus at a rate forty times faster than will I_2."

Chang[1] found that the relative cysticidal efficiency of HIO is one-third that of I_2 at 6°C. and one-half that of I_2 at 25°C.

While we have already noted that there will be little or no tri-iodide ion, I_3^-, present in pool water under any presently approved technology, it is well to note in passing that it has little or no germicidal or virucidal action and only slight cysticidal activity, about one-eighth that of I_2. The iodate ion, which will be present in appreciable concentrations only if pool pH values are maintained at too high a level (pH $>$ 8.2), has no bactericidal, cysticidal or virucidal properties.

Results of Swimming Pool Studies Employing Iodine

During the summer of 1958, Black, Lackey and Lackey[8] conducted a study of the effectiveness of I_2 for the disinfection of swimming pool water in Gainesville and Miami, Florida, employing eight pools varying in size from the Olympic-size pool of the University of Florida to small motel pools and in bather loads over 1,700 persons per day to as low as three persons per day. The procedure used was to release I_2 from added potassium iodide with small dosages of either chlorine gas or hypochlorite solution. These workers found that:

"1. When compared upon the basis of halogen residuals in the range usually employed in swimming pools, I_2 was fully effective in the disinfection of the water of the eight swimming pools treated. It was not only equal to chlorine, but in many cases superior.

"2. To maintain the desired I_2 residual, particularly in pools with high bathing loads, required a much smaller applied dosage than was true of chlorine. Such I_2 dosage was only slightly higher than that required for the disinfection of a home-type pool with a low bathing load.

"3. To phrase the above conclu-

Table I

Percent of Free Available Chlorine

pH	Molecular Chlorine	Hypochlorous Acid	Hypochlorite Ion
4	0.5	99.5	0
5	0	99.5	0.5
6	0	96.5	3.5
7	0	72.5	27.5
8	0	21.5	78.5
9	0	1.0	99.0

Read these important excerpts from the Research Report by Prof. A. P. Black, University of Florida, as published in the July, 1960 issue of Water & Sewage Works . . .

RESULTS OF SWIMMING POOL STUDIES EMPLOYING IODINE!

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"1. When compared upon the basis of halogen residuals in the range usually employed in swimming pools, I_2 was fully effective in the disinfection of the water of the eight swimming pools treated. It was not only equal to chlorine, but in many cases superior.

"2. To maintain the desired I_2 residual, particularly in pools with high bathing loads, required a much smaller applied dosage than was true of chlorine. Such I_2 dosage was only slightly higher than that required for the disinfection of a home-type pool with a low bathing load.

"3. To phrase the above conclusion in another way, I_2 residuals appear to be much less dependent upon bather load than do chlorine residuals. This might be expected because I_2 does not form substitution compounds with ammonia as does chlorine. One may conclude from this statement, therefore, that at the beginning of a bathing peak, a given I_2 residual might be safer than the "free" chlorine residual since there exists the strong possibility that the "free" chlorine residual might quickly be converted to a much less effective chloramine residual, whereas the I_2 residual would not be affected by ammonia introduced by swimmers.

"4. No odors or tastes or irritations of the eyes of bathers were produced by the I_2 residuals employed during the course of these studies.

"5. Although most of the studies were conducted during the hot summer months with high temperatures predominating in seven of the pools, no visible growths of algae were noted during the testing period.

"6. When I_2 was uniformly distributed throughout the swimming pool either through the recirculation system or otherwise, no brown I_2 color was observed, the over all effect being the production of a pleasing aquamarine green color in the swimming pool water."

During the summer and fall of 1960, Black investigated the effectiveness of hypoiodous acid*, HIO, for the disinfection of the water of two hotel swimming pools in Bal Harbour, Miami Beach, Florida—one a fresh water pool, the other containing salt water. In this study HIO residuals were produced by the addition of potassium iodide, KI, and an oxidizing agent. The oxidizing agent used was active over a 24 hour period so that one application daily first released the desired dosage of approximately 20 per cent I_2 and 80 per cent HIO and then re-oxidized the KI formed by the reduction of the two active agents, thus making possible its re-use in a cyclic process. During the two weeks of the test the quality of the water in both pools was such as to meet not only Public Health Service swimming pool standards, but also Public Health Service drinking water standards. It was found possible to effectively disinfect the pools without the production of any color. As was the case in previous studies, no tastes, odors, or eye irritations were present and algal growths did not develop during the period of the test. The treatment was well received by pool users.

* *The material used was*

HIO-DINE

Mfd. by **VOLDALE, INC.**

"HIO-DINE" is Voldale, Inc.'s Trademark for its brand of normally stabilized iodide, HIO & I_2 yielding pool water disinfectant.

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We are interested in Hio-dine for a _____ day trial. Our Swimming Pool is _____ ft. x _____ ft. of _____ gal. capacity, with an approximate daily bather load of _____.

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CITY _____ STATE _____

sion in another way, I_2 residuals appear to be much less dependent upon bather load than do chlorine residuals. This might be expected because I_2 does not form substitution compounds with ammonia as does chlorine. One may conclude from this statement, therefore, that at the beginning of a bathing peak, a given I_2 residual might be safer than the "free" chlorine residual since there exists the strong possibility that the "free" chlorine residual might quickly be converted to a much less effective chloramine residual, whereas the I_2 residual would not be affected by ammonia introduced by swimmers.

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In 1959, Black and co-workers[9] reported on the use of I_2 in small home pools lined with vinyl plastic. The bathing loads, mostly children, varied up to a maximum of 30 each day. In this, as in the preceding study, I_2 was found to be effective for the disinfection of swimming pool water.

Marshall, McLaughlin and Carscallen[10] reported on the practicability of I_2 as a disinfectant in a large cooperative community pool in Adelphi, Maryland. In their summary and conclusions they state:

"Iodine was at least as effective as chlorine for the disinfection of swimming pool waters in the volume studied in this report. Iodine did not form complexes with nitrogenous compounds which were irritating to the eye and nucosa of the nose of a substantial number of bathers.

"No difficulties were encountered in the operation of an iodine-disinfected pool with maintenance of free iodine in the range of 0.2-0.6 ppm.

"Due to a decrease in eye irritation, and despite the noticeable color change, a majority of bathers (68.3 per cent) preferred iodine treated water to chlorine treated water."

During the summer and fall of 1960, Black investigated the effectiveness of hypoiodous acid*, HIO, for the disinfection of the water of two hotel swimming pools in Bal Harbour, Miami Beach, Florida—one a fresh water pool, the other containing salt water. In this study HIO residuals were produced by the addition of potassium iodide, KI, and an oxidizing agent. The oxidizing agent used was active over a 24 hour period so that one application daily first released the desired dosage of approximately 20 per cent I_2 and 80 per cent HIO and then re-oxidized the KI formed by the reduction of the two active agents, thus making possible its re-use in a cyclic process. During the two weeks of the test the quality of the water in both pools was such as to meet not only Public Health Service swimming pool standards, but also Public Health Service drinking water standards. It was found possible to effectively disinfect the pools without the production of any color. As was the case in previous studies, no tastes, odors, or eye irritations were present and algal growths did not develop during the period of the test. The treatment was well received by pool users.

During the summer of 1960, HIO was also successfully used by Marshall in the University of Maryland pool, by Stevenson and Wetzler in the University of Denver pool, by Dailey in a municipal pool in Buffalo, New York, and by Kitter in several municipal pools in Philadelphia[11].

*The material used was HIO-DINE, manufactured by Voldale, Inc., Long Island City, New York.

Summary

The properties which would appear to make I_2 attractive as a disinfecting agent for swimming pool water are these.

1. Use in a large number of swimming pools over extended periods of time has demonstrated its effectiveness as a germicide over a wide range of pH values.

2. It does not combine with ammonia to form iodoamines.

3. Its relatively low chemical activity makes it somewhat less dependent upon bathing loads and organic matter present in the water than other halogens.

4. Used in the form of HIO no color is produced in the pool water.

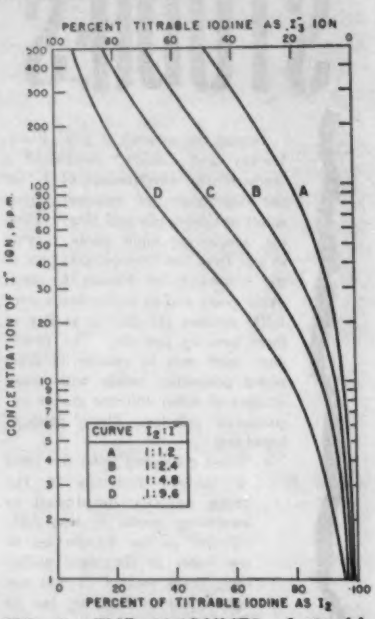

FIG. 2. THE AMOUNTS of titrable iodine I_2 and I_3^- in acidic solutions at 25°C and at varying I_2 : I^- molar ratios.

Table 2

Percent of I_2 Residual of 0.5 ppm Present

pH	I_2	Hypoiodous Acid, HIO	Hypoiodite Ion, IO^-
5	99	1	0
6	90	10	0
7	52	48	0
8	12	88	0.005

5. Odors and tastes are absent and irritation of the eyes of bathers does not appear to result from its use.

6. Lackey, of our research group, has carried out an extensive evaluation of chlorine and I_2 as algaecides and this work, now being readied for publication, shows the two to be about equally effective.

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An Improved, Short-Term, BOD Test

by A. W. BUSCH, Asst. Prof., Dept. of Civil Engineering Rice University Houston, Texas

■ TO EVALUATE THE EFFECTIVENESS of treatment processes and to avoid the creation of nuisance conditions in streams by discharge of excessive amounts of putrescible substances, some broadly applicable measure of the "strength" of organic wastes is necessary. The most important single characteristic from the standpoint of water pollution control and waste treatment is the amount of oxygen required for biological stabilization. This value, termed *Biochemical Oxygen Demand* and commonly spoken of as *BOD,* is determined as a standard procedure by incubating appropriate samples for five days at 20° Centigrade and establishing the amount of oxygen utilized in various dilutions. The oxygen utilization is due to the aerobic action of micro-organisms, principally bacteria and protozoa, feeding upon the organic constituents of the waste. Valid results from such a test are obviously dependent upon the presence in the incubated sample of organisms which are able to attack and break down the organic compounds. The presence of such organisms is insured by seeding the diluted sample with micro-organisms prior to incubation.

Some fifty years ago when domestic sewage was the only wastewater of significance, investigators discovered that the day-to-day progression of BOD in an incubated sample in many instances conformed closely to the graphic path of a first-order reaction equation.

A plot of experimental data with BOD exerted as the ordinate versus time as the abscissa shows, for sewage, a curve which can be expressed mathematically by an exponential function formulation. Figure 1 shows an idealized BOD curve for a "normal" domestic sewage. Expressing the reaction in words: the rate of biochemical oxidation or organic matter is proportional to the remaining concentration of oxidizable material. This proposition is based on the assumption that the amount of available oxygen is not limiting. A first-order equation implies a constant rate of reaction; in other words, a constant percentage of the remaining material is oxidized, or consumed, daily. For many years it was a widely accepted belief that the rate constant, or "k" value, of domestic sewage was essentially stable at a value of 0.1 for common logarithms, corresponding to a stabilization rate of 21 per cent of the remaining food per day. As evidence accumulated, it became apparent that the rate constant did vary from test to test. Since variations in "k" are most significant during the early portion of the incubation period, and were attributed largely to initial differences in the microbial seed population, the use of the 5-day incubation as the standard procedure became more entrenched. It was felt that by five days' time the variations in microbiological activity would be minimized and that consistent results would be attainable. Figure 2 shows how widely varying velocity constants can yield identical 5-day results.

It is pertinent to point out here that the concept of a first-order reaction occurring in an environment occupied by a heterogeneous microbial population feeding on organic material of widely varying composition and form is at variance with all established knowledge related to microbial metabolism. A number of investigators have commented on this anomaly, including the man who first formulated the equation. However, experimental data repeatedly verified the correlation for domestic sewage, and certainly the concept of a rate constant is extremely useful in forecasting the effect of a waste on downstream conditions. While the 5-day BOD value may be adequate for comparing wastes on a relative basis or for evaluating the effectiveness of a treatment plant, the characteristic of importance in water pollution control is the total load on the stream or the so-called ultimate BOD. For practical purposes this is usually considered to be the 20-day BOD. Figure 3 contains the data of Figure 2 plotted to a different scale and extrapolated to the 20-day value. The fallacy of a given waste being oxidized at different rates and yet producing a fixed 5-day BOD value

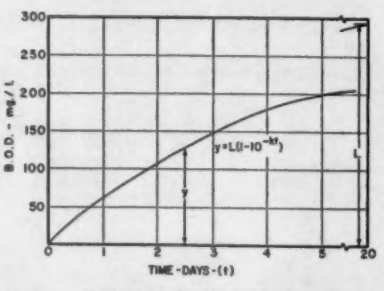


Fig. 1. IDEALIZED First-Order BOD Curve with k=0.1, and L=293.

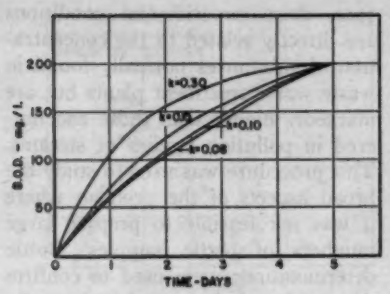


Fig. 2. FIVE-DAY BOD curves with various velocity constants.

is clear since logically a given waste must have a reproducible ultimate BOD. Following this line of reasoning leads to the presentation in Figure 4 showing that the 5-day BOD must vary with the rate constant since a fixed amount of oxidizable organic matter is present. It should be re-emphasized here that the whole concept of a valid 5-day BOD test is predicated upon the 5-day value representing a constant percentage of the ultimate oxygen demand.

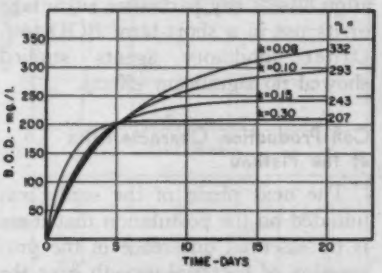


Fig. 3. EFFECT OF VELOCITY constant k on 20-day BOD L with fixed 5-day BOD. (After C.N. Sawyer, 1951)

Obviously a test requiring five days of incubation prior to analysis of samples has definite limitations. In other words, samples of a plant effluent taken on Monday cannot be analyzed until Saturday. By that time, the sampled effluent is well downstream. Many workers during the forty years since the test was established have attempted to modify the procedure and shorten the time required but with no success. During the last decade particularly, the technical literature has carried much information casting doubt on the validity of the first-order assumption used in comparing the "strength" of organic wastes and in predicting the rate of biological stabilization of putrescible matter in polluted waters. A high percentage of these papers were concerned with industrial wastes, particularly those containing predominantly dissolved organics.

Basis of Study[1,2,3]

In the fall of 1957, a project having as its objectives the detailed delineation of the actual progression of oxygen utilization in soluble organic substrates and the establishment of a valid short-term BOD test for such substrates was initiated at Rice University. The basis for the investigation was experimental data published by the writer in 1952[4]. It was mentioned previously that the 5-day BOD value was established as the standard yardstick since shorter incubation times were considered unreliable due to initial variations in microbial activity. Table I shows daily BOD values obtained in work involving a highly reproducible soluble substrate. These data, comprising some 660 individual analyses, show that the 1-day BOD values were by far the most reliable parameter. The daily increase in the coefficient of variation is of particular interest. It is also noted that the rate constant "k" calculated from the experimental data showed a variation of 44 percent, while the experimentally determined ultimate BOD values ranged from 133 to 279 mg/l. The only variable in this work was the seed population used in successive experiments. Figure 5 shows graphically the progressively increasing range of daily BOD values.

Theory of BOD Progression

On the basis of these and subsequent experiments, a theory was propounded which ascribed the progressive variation in BOD values to

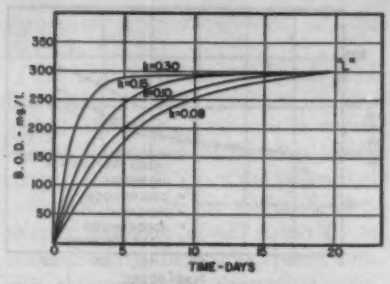


Fig. 4. EFFECT OF VELOCITY constant k on 5-day BOD with fixed 20-day BOD L. (After C.N. Sawyer, 1951)

the effect of varying ratios of bacteria to higher organisms in the seed population. In other words, soluble compounds are readily available to the bacteria and are quickly consumed,

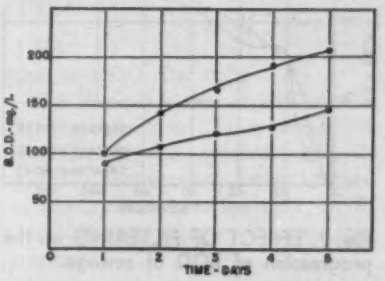


Fig. 5. RANGE OF DAILY BOD values for a synthetic sewage.

probably within 24 hours. Subsequent utilization of oxygen in excess of the respiratory requirements of the bacteria was attributed to the activity of higher organisms feeding on the bacteria. According to this theory, the higher the initial ratio of predator organisms to bacteria in the seed, the higher the 5-day BOD value. That this is a valid proposition was demonstrated experimentally

Table I

BOD Data for a Synthetic Sewage

EXP. NO.	Daily BOD Values 1	2	3	4	5	"K"	"L"
1	95	116	157	190	190	0.161	234
2	94	107	157	186	194	0.109	279
3	99	142	167	182	187	0.310	193
4	90	120	164	178	185	0.218	206
5	92	140	162	162	182	0.313	178
6	97	115	129	146	164	0.304	160
7	96	107	121	152	158	0.187	180
8	92	110	123	128	147	0.539	133
9	100	125	164	188	208	0.184	236
10	98	128	156	192	195	0.179	230
11	96	125	164	182	197	0.209	216
$Cv = \frac{\sigma}{M}$	0.03	0.09	0.11	0.12	0.10	0.44	0.18

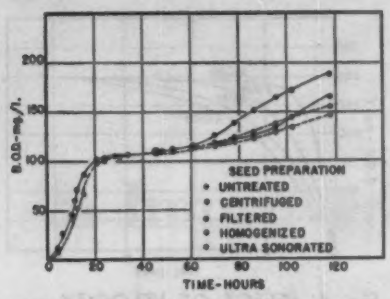


Fig. 6. BOD CURVES for a synthetic sewage direct method.

as shown in Figure 6. All samples agreed through 60 hours and, following initiation of predator activity, the sample containing the seed which

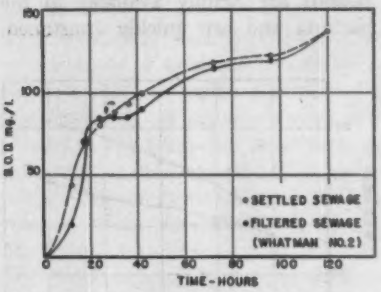


Fig. 7. EFFECT OF FILTERING on the progression of BOD of sewage.

had not been altered physically yielded the highest 5-day BOD value. As a further demonstration of the effect of predator organisms, filtered

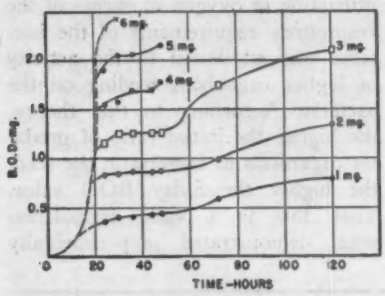


Fig. 8. PROGRESSION OF BOD for various glutamic acid concentrations.

and unfiltered samples of domestic sewage which had been settled to remove suspended matter were used to determine the BOD progression. Figure 7 shows clearly how the typical first-order curve noted so often for domestic sewage can be altered by disturbing the bacteria-predator balance. It is interesting to note that the 5-day BOD values are identical.

Reproducibility of Plateau

Having established that the progression of BOD in soluble substrates is a two-stage and not a first-order reaction, efforts were concentrated on determining whether the plateau representing conversion of food into bacterial cells was reproducible for a given compound. A correlation between plateau oxygen demand values and theoretical BOD was established for several pure compounds. Figures 8 and 9 show the results of a typical experiment.

Use of Plateau

With the establishment of the validity of the first-stage plateau as a reproducible percentage of the theoretical BOD, a study was initiated to determine the possibility of increasing this percentage by selective poisoning of the bacterial assimilatory processes using the technique developed by Clifton[5]. The result of blocking assimilation would be an increased respiration and thus a higher ratio of plateau values to theoretical BOD. The relation between respiration and assimilation is presented diagrammatically in Figure 10.

In the investigation, both manometric and bottle dilution techniques were employed for the determination of BOD values. The manometric

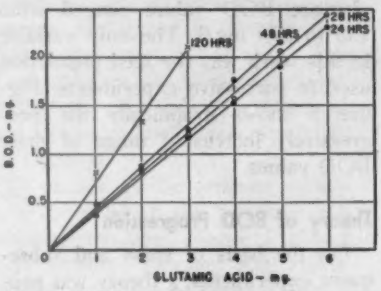


Fig. 9. BOD vs. glutamic acid.

procedure requires the use of relatively high concentrations of both substrate and seeding organisms. Therefore, these experimental conditions are directly related to the concentration of substances normally found in waste water treatment plants but are markedly higher than those encountered in pollution studies of streams. This procedure was used to study the broad aspects of the problem where it was not feasible to prepare large numbers of bottle samples. Bottle determinations were used to confirm the results of the manometric method in dilutions applicable to stream conditions. It is seen that the techniques employed encompass the broad realm of biological oxidation, from waste treatment plant design to pollution control studies.

Typical results are shown in Figures 11 through 15. The sensitivity of the phenomenon of respiration stimulation is especially apparent in Figure 13. Although substantial increases in plateau values were obtained for glucose, glutamic acid, and a 1:1 mixture of these, in combination with sodium azide, the lag induced by partial inhibition of respiration offsets any particular advantage of its use in a short-term BOD test. Other inhibitory agents studied showed no significant effects.

Cell Production Characteristics at the Plateau

The next phase of the study was initiated on the postulation that there is no essential difference in the progression of bacterial growth over the broad range of environments encountered in industrial waste treatment and water pollution control. There should be basic parameters relating the areas of pollution measurement, waste "strength", biological treatment and receiving water self-purification. Investigators have generally approached these problems as

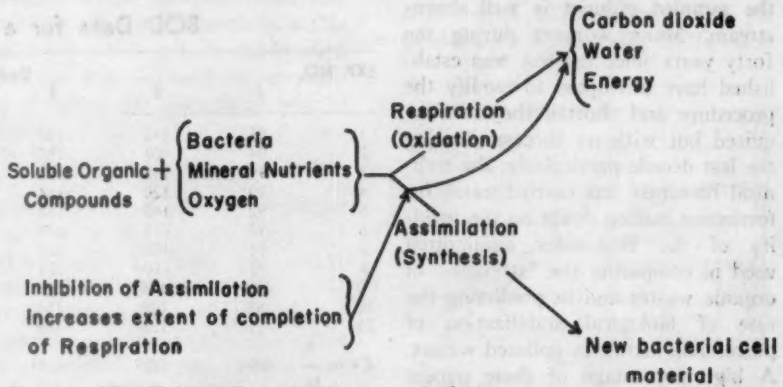
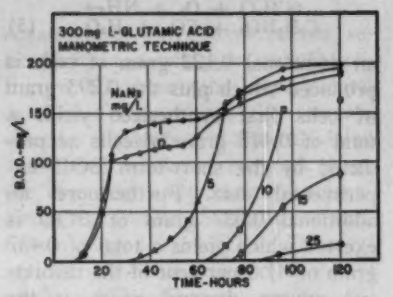
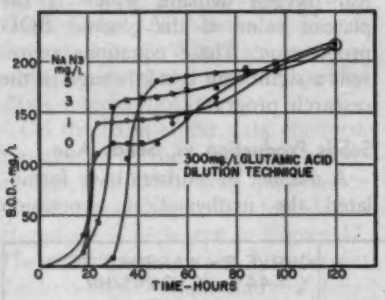
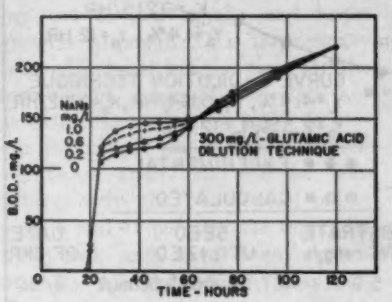
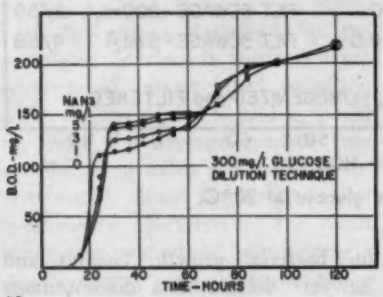


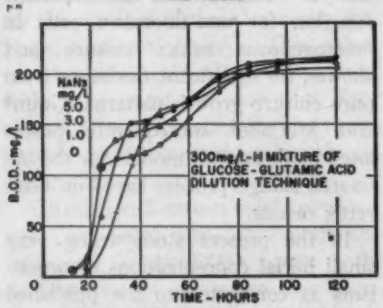
Fig. 10. RELATION OF respiration to assimilation.











Figs. 11-15. TYPICAL stimulation curves.

separate entities. There follows theoretical and experimental evidence, supported by mathematical and biochemical formulations, of the interrelation of these areas of study.

The reproducibility of the plateau in oxygen utilization for a particular substrate has been mentioned previously. Workers in the field of microbiology have reported similar results in pure culture studies. In addition, investigators studying activated sludge have commented on the reproducibility of cell production under controlled experimentation. It follows logically that, since the plateau in oxygen utilization in the BOD bottle represents conversion of substrate into cells, there should be a correlation between short-term BOD and bio-oxidation solids production under conditions of similar solids age. Such a correlation, based on biochemical reactions, presupposes a permissible general formulation for cell material.

Statistical Reliability of Plateau

A statistical analysis was made of the short-term BOD test values for the two primary 5-day standards. (See Table II). Seed from two sources was utilized with each substrate. Each statistical analysis was based on twelve replicate runs using three substrate dilutions. Hence, N has a value of 36. The short-term BOD incubation period selected was 36 hours. This time was chosen on the basis of data, reported previously[1] showing that for the substrate and seed concentrations in use, complete linearity for glucose was assured. For glutamic acid, 24 hours could have been just as well utilized.

These data indicate that a plateau value of 132 mg/l for a 300 mg/l glucose solution is quite reproducible. This represents 41.1 per cent of the theoretical oxygen demand of the glucose.

The next step was a delineation of the mode of solids synthesis in biological oxidation of glucose in exerting 41.1 per cent of the theoretical oxygen demand. Since the postulated theory holds that the plateau represents conversion of all substrate to bacterial cells, these cells should contain the remaining theoretical oxygen demand. Porges, *et al.*,[6] have suggested a general formula of $C_5H_7NO_2$ for mass mixed cultures. The general reaction can be written as:

$$A \cdot C_6H_{12}O_6 + B \cdot O_2 \rightarrow X \cdot C_5H_7NO_2 + Y \cdot CO_2 + Z \cdot H_2O \quad (1)$$

Thus the cells should represent: $\frac{1-0.411}{1.414^*} = 0.416$ g of solids per gram of BOD removed.

The three possible modes of solids synthesis are: 1. synthesis of cells directly; i.e., growth only, 2. oxidative conversion into another carbohydrate, respiration only, or 3. a combination of growth and respiration.

Synthesis alone can be considered as:

$$C_6H_{12}O_6 + O_2 + NH_3 \rightarrow C_5H_7NO_2 + CO_2 + 4H_2O \quad (2)$$

However, this reaction indicates 0.591 grams of cells per gram of theoretical oxygen demand and only 16.67 per cent of the theoretical oxygen demand is exerted.

Considering only respiration:

$$C_6H_{12}O_6 + (1-5)\ O_2 \rightarrow (5-1)CH_2O + (1-5)CO_2 + (1-5)H_2O \quad (3)$$

*$C_5H_7NO_2$ has a theoretical OD of 1.414 gm/gm.

Table II

Statistical Analysis* of Reproducibility of Short Term BOD

Substrate**	Seed*	BOD 36 HR	BOD 120 HR	σ 36 HR	σ 120 HR	$\frac{\sigma}{M}$ — % 36 HR	$\frac{\sigma}{M}$ — % 120 HR
Glucose	1	131.8	221.5	2.61	1.84	1.98	0.80
Glucose	2	132.0	220.6	2.09	2.67	1.58	1.21
Glutamic Acid	1	123.7	217.8	2.57	2.03	2.08	0.93
Glutamic Acid	2	123.0	217.8	2.37	2.05	1.93	0.94

* Each analysis based on 12 experiments of 3 dilutions each, i.e., N = 36

** All 300 mg/l.

* Seed 1—West University Place, Texas, Sewage, 5 ml/l., Filtered
Seed 2—Bellaire, Texas, Sewage, 5 ml/l., Filtered

Dilutions used: 5, 7, 9 ml 300 mg/l Solution per bottle
Substrate Concentrations: 1.50, 2.10 and 2.70 mg/Bottle; 4.84, 6.77 and 8.71 mg/l.

Table III

Correlation of Short-Term BOD and Solids Production in Glucose Oxidation*

Glucose Concentration: 500 mg/l, Warburg Technique
Sample Volume: 40 ml.
500 mg/l x 40 ml = 20 mg Glucose = 21.4 mg Theor. OD

Maximum Solids Production: (at max Carbohydrate)
Predicted: 21.4 mg x 0.49 = 10.49 mg.
Observed*: 265 mg/l x 0.04L = 10.60 mg.

Solids Production at Maximum Protein level:
Predicted: 21.4 mg x 0.42 = 9.0 mg.
Observed*: 164 mg/l x 0.04L = 9.0 mg.
*Using data of Gaudy and Engelbrecht[6a,b]

In this reaction solids production and oxygen utilization can proceed only in increments of 16.67 per cent which is not a multiple of 41.

Writing the reaction for a combination of respiration and growth:

$$8C_6H_{12}O_6 + 18O_2 + 4NH_3 \rightarrow 10CH_2O + 4C_5H_7NO_2 + 18CO_2 + 30H_2O \quad (4)$$

The reaction is governed by the respiratory quotient of glucose which has a value of 1. The equation shows:
0.195 gram of CH_2O produced per gram of theoretical oxygen demand removed,
0.293 gram of $C_5H_7NO_2$ produced per gram of theoretical oxygen demand removed,
0.488 gram of solids produced per gram of theoretical oxygen demand removed,
and 0.4 gram or 37.5 per cent of the theoretical oxygen demand is exerted.

At this point the substrate has obviously been consumed insofar as soluble BOD is concerned. However, as the stored carbohydrate is oxidized to cells,

$$6CH_2O + O_2 + NH_3 \rightarrow C_5H_7NO_2 + CO_2 + H_2O \quad (5)$$

an additional 0.122 gram of cells is produced which plus the 0.293 gram of cells first synthesized yields a total of 0.415 gram of cells as predicted by the short-term BOD experimental data. Furthermore, an additional 0.037 gram of BOD is exerted which yields a total of 0.437 gram or 41.0 per cent of the theoretical oxygen demand which is the plateau value of the glucose BOD progression. These equations represent a significant breakthrough in the research program.

Solids Production vs. Solids Age

A number of workers have formulated the mathematical expression

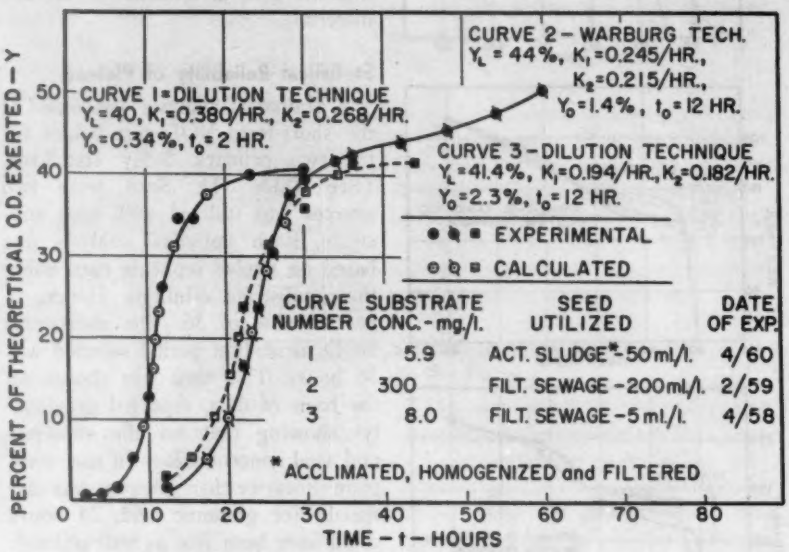

CURVE 2 – WARBURG TECH.
Y_L = 44%, K_1=0.245/HR., K_2=0.215/HR., Y_0=1.4%, t_0=12 HR.
CURVE 1=DILUTION TECHNIQUE
Y_L=40, K_1=0.380/HR., K_2=0.268/HR. Y_0=0.34%, t_0=2 HR.
CURVE 3 – DILUTION TECHNIQUE
Y_L=41.4%, K_1=0.194/HR., K_2=0.182/HR. Y_0=2.3%, t_0=12 HR.
EXPERIMENTAL
CALCULATED
CURVE NUMBER | SUBSTRATE CONC.-mg./l. | SEED UTILIZED | DATE OF EXP.
1 | 5.9 | ACT. SLUDGE*-50 ml/l. | 4/60
2 | 300 | FILT. SEWAGE -200 ml/l. | 2/59
3 | 8.0 | FILT. SEWAGE -5 ml/l. | 4/58
*ACCLIMATED, HOMOGENIZED and FILTERED
PERCENT OF THEORETICAL O.D. EXERTED – Y
TIME – t – HOURS

Fig. 16. BOD PROGRESSION curves for glucose at 20°C.

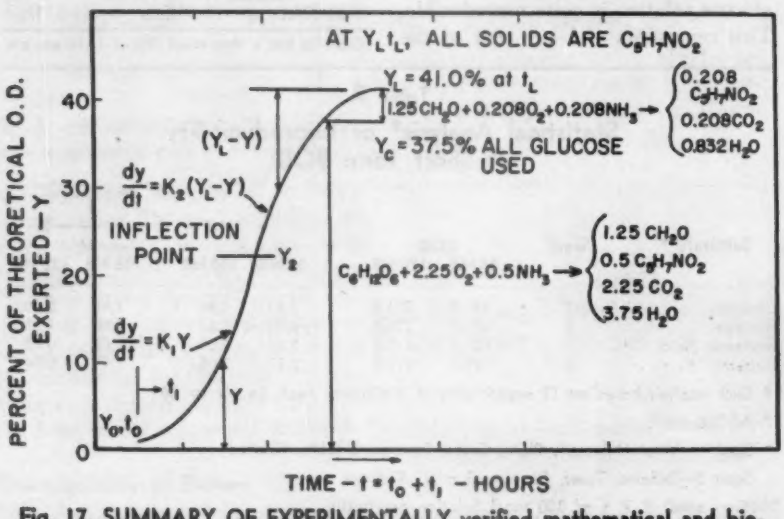

AT $Y_L t_L$, ALL SOLIDS ARE $C_5H_7NO_2$
Y_L = 41.0% at t_L
$1.25CH_2O + 0.208O_2 + 0.208NH_3 \rightarrow$ 0.208 $C_5H_7NO_2$, 0.208 CO_2, 0.832 H_2O
Y_c = 37.5% ALL GLUCOSE USED
$(Y_L - Y)$
$\frac{dy}{dt} = K_2(Y_L - Y)$
INFLECTION POINT
Y_2
$C_6H_{12}O_6 + 2.25O_2 + 0.5NH_3 \rightarrow$ 1.25 CH_2O, 0.5 $C_5H_7NO_2$, 2.25 CO_2, 3.75 H_2O
$\frac{dy}{dt} = K_1Y$
t_1
Y
Y_0, t_0
PERCENT OF THEORETICAL O.D. EXERTED – Y
TIME – $t = t_0 + t_1$ – HOURS

Fig. 17. SUMMARY OF EXPERIMENTALLY verified mathematical and biochemical progression of bacterial degradation of glucose.

for bacterial growth. Garrett and Sawyer[7] delineated a discontinuous function for non-flocculent cells in heterogeneous mass culture and showed no significant deviation from pure culture growth patterns. Gram[8] and McCabe[9] subsequently postulated mathematical models for the activated sludge process based on Garrett's results.

In the present study using very small initial concentrations of organisms as contrasted to the published mass culture work, the use of a continuous function identical to that used in forecasting the growth and limits of any biological population was elected. This procedure was tested by applying a continuous function composed of two exponential

equations to three experiments selected from a two-year compilation. Figure 16 shows the experimental data used to evaluate the reaction velocity constants and the calculated data based on these constants. Note the divergent experimental environments represented. Substrate concentration ranged from 5.9 to 300 mg/l with seed concentrations of 5 to 200 mg/l; ranging from sewage to activated sludge. All seed was filtered through No. 2 Whatman paper to minimize predator and suspended solids interference.

On the basis of the data obtained, a summary of the postulated mathematical and biochemical progression of the aerobic bacterial degradation of glucose is presented in Figure 17. The coordinates y_o and t_o represent the first experimental analysis showing net oxygen uptake and hence growth. Although Y_L is theoretically reached only at infinite time for the formulation proposed, the data approach sufficiently close to Y_L to permit the use of the equation without significant error. As will be seen subsequently, the two control points of 37.5 and 41 per cent are especially significant and have been experimentally substantiated in mass cultures.

If the curves described by the postulated continuous function were symmetrical about the inflection point, the average of k_1 and k_2 would represent the average growth rate and the mean solids age could be approximated. Since symmetry is not a necessary characteristic the mean solids age would be more nearly represented by $\bar{t}$, the time coordinate for the centroid of the area under the curve, measured from t_o. This value can be mathematically determined, with some effort, as shown in Figure 18. Data are plotted for the three experiments delineated previously in Figure 16.

Correlation between solids production in bench-scale bio-oxidation units and in the BOD bottle, both as functions of solids-age, has been presented in detail elsewhere[3]. However, the best evidence of the validity and reproducibility of the relationship between short-term BOD and bio-oxidation solids production is shown in Table III. Here data published by Gaudy and Engelbrecht [10] for Warburg studies using mass heterogeneous cultures of acclimated organisms are used to check the validity of predictions based on the theory presented herein. At the two check points of 37.5 and 41 per cent of the theoretical oxygen demand, predicted values of 10.49 and 9.0 are compared to observed values of 10.60 and 9.0 milligrams of solids produced per milligram of theoretical oxygen demand removed.

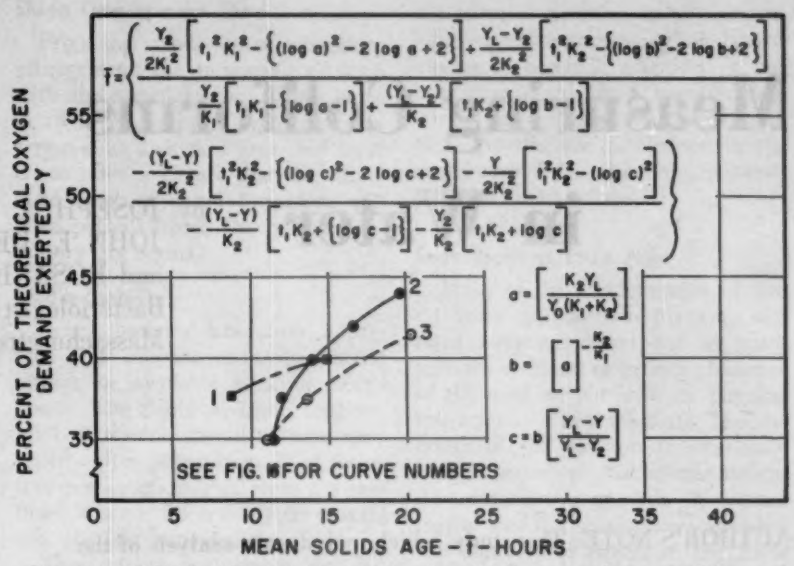


Fig. 18. MATHEMATICAL formulation for BOD progression vs. solids age at 20°C.

Current and Future Work

This report includes work done under NIH Research Grant RG5534. Current work is directed toward the utilization of the information presented for attainment of a 24 hour total oxygen demand test. Future work will be concerned with validation of the procedure for various heterogeneous waste waters.

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Measuring Coliforms in Water

by JOSEPH A. McCARTHY, Chief
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AUTHOR'S NOTE: This study, which includes an analysis of the discrepancies encountered with the use of the membrane filter and a proposed technique, is supported in part by a grant from the National Institutes of Health to the Massachusetts Health Research Institute.

Introduction

■ THE SPECIFIC AIM of this research project as submitted to the NIH was "to assess the possibility of obtaining results by the membrane filter technique which are statistically equivalent to the standard multitube technique for the estimation of the sanitary quality of water, using coliform bacteria as a parameter."

Our previously published data on this and related projects[1, 2, 3, 4] indicated quite conclusively that the lack of agreement reported between the membrane filter and the multitube technique is due to the inability of presently available media with the present technique to provide a uniform growth of all members of the coliform group resulting in uniform recognizable appearance within a convenient and uniform incubation period.

A procedure has been developed at the Lawrence Experiment Station, as a result of the work under the grant, which affords much greater and much more nearly uniform recovery of all the coliform types found in water samples than any combination of medium and technique previously tested. This has resulted from critical studies of the behavior of the various members of the group and particularly of their growth characteristics on various media.

Disadvantages of the One-Step Endo Broth Technique

The original membrane filter technique included an enrichment period followed by transfer of the filter to a selective medium for final incubation. Later, many media were proposed which were reported to provide satisfactory results in a simpler one-step incubation[6, 7, 8, 9]. There is, naturally, a preference for the simpler technique, but close scrutiny has shown the following inherent disadvantages in its use.

Suppressive Effect

The bacteria lodged on the surface of the filter are intimately bathed in the relatively high concentration of fuchsin and sulfite. This environment has been found extremely detrimental to the weaker coliforms, with actual kills of a large part of the species in a short period. Laboratory experiments demonstrate this effect[10].

To determine the suppressive effects of M-Endo broth[11] on coliform bacteria, we used the following laboratory procedure. Pure culture suspensions were prepared and a sizeable number of coliform bacteria were inoculated into full strength M-Endo broth. The initial coliform density ranged from 50 to 100 per ml, which is relatively equal to the count per unit volume of medium desired on a countable membrane filter. For control purposes, a similar inoculum was added to lauryl tryptose broth.[12] The initial densities produced by the inocula were determined by averaging five replicate agar plates, then the bacterial suspensions were incubated at 35°C and at the end of one, and again at the end of two hours, five replicate agar plates were planted from the two broths. The data from 20 such investigations are presented in Table 1.

This presentation shows that M-Endo broth during the first hours of contact affects to a great degree the survival and consequently the eventual number of various members of the coliform group. The magnitude

Table 1

Growth Studies of Various Coliform Members

Per Cent of Initial Density

Culture	Lauryl Tryptose		M-Endo Broth	
	After 1 hr	After 2 hr	After 1 hr	After 2 hr
+ + − −	124.5	240.	105.	216.
+ + − −	100.	229.	100.	201.
+ + − −	100.	100.	76.2	72.
+ + − −	107.	201.	102.	196.
+ + − −	104.	197.	55.	100.
+ + − −	115.	225.	107.	206.
− + − −	103.	104.	94.	77.5
− + − −	113.	126.	66.8	72.3
− + − −	95.	92.	68.3	74.0
− + − +	101.5	107.	62.8	82.5
− + − +	106.	106.	77.5	88.8
− + − +	106.	114.	28.2	42.0
− + − +	100.	120.	35.2	73.0
− − + +	98.5	122.	14.1	20.2
− − + +	106.	128.	65.4	87.0
− − + +	116.	149.	68.7	69.7
− − + +	103.	103.	42.6	36.4
− − + +	93.5	91.	64.5	55.0
− − + +	104.	130.	57.3	63.0
− − + +	109.	116.	75.1	80.4

of this effect varies with the species. Thus, the response of different type waters to M-Endo broth in the one-step technique will fluctuate depending upon the numbers and types of coliform species present in the water. This pattern of response has been consistently found in actual practice.

In the early stages of research, it was believed that the most fruitful field for this project to investigate would be in regard to better cultivation of the coliform types able to grow on the M-Endo medium but not able to form sheen. Carbohydrate compounds and bacterial stimulants were added to M-Endo broth without too much success. The carbohydrates were able to assist some weak growers to form sheen, but they also fostered prolific growth of the rapid fermenters with dissolution of the sheen. The carbohydrate compounds were unable to mask the suppressive effect of the fuchsin sulfite environment. Successive reductions in the concentrations of sulfite and fuchsin indicated that the level which was non-toxic to these coliform types was below the concentrations necessary for the production of sheen in a liquid system.

It was gradually realized that in great part the failure of many coliform types to reach full development with the one-step techniques was not that they were prevented from developing a sheen, but that the liquid Endo environment either greatly delayed normal growth or actually killed the organisms.

Diffusion Effect

There are at least two conditions associated with the liquid phase environment of the Endo broth which can be expected to be unfavorable to coliform growth or identification.

1. The liquid phase is favorable to rapid diffusion of any inhibitory by-products of the effects of metabolism on the materials in the medium, with toxic effects on any individuals of the slow growing or susceptible coliform type which were fortunate enough to survive the initial shock of the fuchsin-sulfite environment.

2. The ready diffusibility of food through the liquid phase encourages a practically unlimited growth of the more hardy and rapid fermenters to the stage where the identifying sheen is quickly destroyed by overgrowth and at the same time the weaker types are unable to compete for food.

Sheen Development Time

From the standpoint of laboratory management, the optimum growth with liquid medium which may come in 18 to 20 hours or even less, may arrive at an awkward time, and there is too often a chance that the short-lived peak of sheen formation will have passed before the normal laboratory day begins.

Media Stability

In any bacterial laboratory, apparatus and supplies of media should always be available at a moment's notice. The liquid M-Endo medium, for best results, should be used very shortly after preparation. It is therefore not practicable to store the medium in a condition ready for instant use, for any extended period.

This critical analysis of the disadvantages of the one-step technique, in spite of its convenience, accentuated the need for a new technique. This is true from the standpoint of best coliform recovery and from the point of view of laboratory management.

Proposed Procedure

Enrichment

The inhibiting and/or bactericidal influence shown by M-Endo broth against weak coliforms in the first hours of incubation strongly suggested the need of an enrichment or resuscitation period. Such a period should provide a non-toxic environment for the gradual adjustment of these weaker organisms. Experiments showed the value in providing this bridge for bacterial life between the environment of the samples and that of the M-Endo ingredients. Extensive trials on all sorts of samples, from sewage to the best tap waters, have indicated that two hours, plus or minus half an hour, is sufficient to provide adequate enrichment for the weakest coliforms. This period is not stimulatory for the most rapidly growing varieties. The time appears to be used entirely for acclimation, with a minimum of logarithmic growth. The same trials showed that normal single strength lauryl tryptose broth was a very satisfactory medium.

The two-step method with enrichment thus appears to present obvious advantages in uniform recovery of all types of coliforms. The sole disadvantage, the necessity of changing the filter from the enrichment to the final selective medium, is not so prohibitively time-consuming or laborious as to preclude adoption; it has been minimized by a procedure in which both phases, enrichment and final growth, are carried on in the same petri dish, with only moments required for transfer.

Endo Broth vs Endo Agar

Many of the disadvantages of Endo broth discussed in previous sections were associated not so much with the chemical or growth character of the medium but with its physical characteristics as a substrate. The viscosity of the medium is essentially that of water, so that almost unlimited diffusion is possible. It seemed logical that if viscosity were adjusted the unfavorable effects of the Endo medium on the weaker organisms might well be reduced. The addition of agar-agar to the basic medium was found at once to show these advantages:

1. Enrichment, plus an agar substrate (E & A), almost without exception produced a higher degree of coliform recovery than the Endo broth one-step technique. In some of the samples, additional recovery ran to several hundred per cent. A detailed analysis of the comparative results is presented in a later section of the report.

2. The sheen produced on colonies grown on the agar medium after enrichment was more pronounced than that on the liquid medium and, instead of fading rapidly, the sheen remained, generally without change, for many hours or even for days after its first appearance.

3. This retention of sheen made it possible and advisable to allow a full overall 24 hours of incubation since the danger of losing the characteristic appearance no longer exists. Colonies which develop the characteristic sheen well before 24 hours will retain their appearance, and the slower forms will be given the longer time apparently necessary. It is, therefore, possible to begin analysis of samples almost any time during the working day with assurance that significant results will be available.

Formulation of Endo Agar

At first, the semi-solid medium

was prepared simply by adding agar to the M-Endo broth. Subsequent investigation showed that considerably less fuchsin-sulfate concentration was required with the agar substrate than was needed with the liquid medium to give at least equal sheen; the relative proportions remained unchanged. Eventually, it was demonstrated that the strength of the M-Endo medium could be reduced by 25% and that 1.5% of agar gave best results. The formulation of the medium which has been labeled L. E. S. Endo agar MF is as follows:

Bacto-Yeast Extract	1.2 g
Bacto-Casitone	3.7 g
Bacto-Thiopeptone	3.7 g
Bacto-Tryptose	7.5 g
Bacto-Lactose	9.4 g
Dipotassium Phosphate	3.3 g
Monopotassium Phosphate	1.0 g
Sodium Chloride	3.7 g
Sodium Desoxycholate	0.1 g
Sodium Lauryl Sulphate	0.05 g
Sodium Sulfite	1.6 g
Bacto-Basic Fuchsin	0.8 g
Agar	15.0 g

To re-hydrate the medium, suspend 51 g and 11 ml of ethyl alcohol in 1000 ml distilled water and heat to an incipient boil; agitation is advisable, cool to 45°—50°C and dispense into the smaller half of 60 cm glass petri dishes or disposable plastic dishes. A four ml portion of the agar is sufficient to provide the necessary depth of medium in these two type vessels. To utilize 100 cm petri dishes, 8 to 10 ml of the agar will be necessary. The agar plates should then be stored in the refrigerator and can be used over a two week period. Prolonged exposure to sunlight will cause an intensification of the color.

Procedure in Detail

In the larger half of the petri dish, an absorbent pad is placed and saturated with lauryl tryptose broth. Approximately 1.7 to 1.8 ml of broth will be sufficient. Excess liquid should be removed since it is prone to produce sloppy end results.

The prepared membrane filter is placed on the saturated pad with a rolling motion to prevent air entrapment. The inverted petri dish is then incubated at 35°C for 2 ± ½ hours.

After the enrichment period, the membrane is stripped from the enrichment pad and rolled onto the surface of the Endo agar in the other half of the petri dish. The enrichment incubation allows the agar mass to acquire the temperature of the enrichment phase, thus the temperature gradient at the moment of transfer is practically eliminated. Incorrect placement of the membrane on the agar is at once obvious, since patches of unstained membrane indicate air entrapment between the agar and membrane. The membrane must then be realigned to achieve total contact. Intimate contact is not a necessity for the periphery outside the filtering area. The used pad may be discarded at this time or may be left in the top section for humidity purposes. The petri dish is again inverted and incubated at 35°C. After 22 hours the sheen colonies are counted, preferably using a stereomicroscope having a light source above, and approximately perpendicular to, the plane of the membrane. Other colonies may be counted, frequently providing valuable information.

Discussion of Results

Selectiveness of New E & A Technique

The marked increase in the numbers of sheen colonies developed by this new membrane analysis method obviously made it necessary to inquire into the genuineness of these additional organisms. Our first progress report on this subject[4] indicated that 100% selectiveness might be beyond realization, but that a satisfactory selective test should guarantee a very large proportion of the colonies presenting characteristic growth should be coliforms.

The percentage of verification achieved by this new technique in a great number of studies compared very favorably with the selectiveness of the M-Endo broth. In fact, in many samples the E & A technique showed a higher degree of selectivity. A representative number of these comparative studies is presented in Table 2.

Table 2

Selectiveness Incorporated into Proposed New Technique

Sample Source	M-Endo Broth Technique		E & A Technique	
	Ave. Ct/100 ml	% Verification	Ave. Ct/100 ml	% Verification
Polluted River	25,200	—	43,000	95
Polluted River	30,900	90	45,300	90
Polluted River	21,600	91	42,800	88
Polluted River	27,000	91	32,400	90
River Water	4,700	88	8,100	88
River Water	5,100	93	5,400	92
River Water	3,600	87	5,600	90
Pond Water	142	87	432	77
Pond Water	112	82	136	97
Pond Water	54	93	124	96
Pond Water	50	81	80	84
Pond Water	32	83	48	83
Pond Water	6.4	89	96	85
Pond Water	120	86	470	87
Pond Water	12	88	57	91

The marked increase in the number of sheen colonies by this new method over a wide field of samples was not obtained at the expense of selectiveness.

Inclusiveness Incorporated into Proposed New Technique

The data reported in Table 3 show the comparative types and numbers of coliforms isolated by the liquid medium and the E & A method, in replicate, from Merrimack River samples. It is shown that the recovery of *E. coli* types is not materially changed, but the total number of various types of Aerobacter grown is almost tripled and the numbers of intermediates is almost doubled by the E & A method. The latter members of the coliform group are specifically those which our earlier work has shown were most apt to be lost in the Endo broth membrane filter procedure. This definitely demonstrated the increase in inclusiveness of the E & A technique as compared to the Endo broth technique.

Further confirmation of the beneficient effect of the E & A has been furnished by comparative inoculations of about one hundred pure cultures of Aerobacter and intermediates with enormously improved survival rates and growth ability being associated with the new procedure.

Table 3

Inclusiveness of New E & A Technique

IMViC Code	Verified Colonies No. of Species Recovered by: MF Endo One-Step Technique	E & A Technique
+ + − −	13	13
− + − −	1	3
− − + +	14	29
− + + +	3	4
− − − +	2	14
+ + − +	4	6
− + − +	6	10
+ − + +	1	3
− − + −	1	4
+ + + +	3	5
+ + + −	1	1
+ − − +	0	1
− + + −	0	1
	49	94

Comparison of the Standard Lactose Broth Method and the Proposed E & A Technique

Drinking Water Analysis

The standard multitube technique for determining the coliform density of drinking water has been subjected to a great deal of discussion, and a fair amount of investigation, since the advent of the MF technique. The criticisms most often leveled against the multitube procedure are:

time required for a decision on the quality of the water[13],
small volume which it is possible to test conveniently,
bias reputedly inherent in the method[14],
often excessive amount of unrewarding laboratory work, and
possibility of overgrowth of the indicator coliform organisms by noncoliforms in the lactose environment.

Proponents of the membrane filter technique stress the comparative advantages for the corresponding points:

analysis can be completed within 24 hours, without verification,
more water can be conveniently examined from a given sample,
MF is a plate count method and, therefore, inherently free of bias in theory; in practice its bias be none or very small,
laboratory manipulations are minimized since fewer false positives are found, and organism is fixed on a plane surface allowing distinct growth of individual colonies, with a minimum possibility of interference.

Comparison of Standard Procedure and Membrane Filter

Of the routine drinking water samples received at the Lawrence Experiment Station during a two month period, 654 were examined in parallel by the standard lactose broth multitube procedure and by the new E & A technique. The samples came from Massachusetts municipal supplies, from Army and Navy facilities and from State recreational areas. The results are shown in Table 4.

For each sample, a volume of 100 ml was taken for examination by MF and the usual five portions of 10 ml each were inoculated into standard broth tubes.

Data indicate that 87% of all the samples were found free of coliform by the MF technique; all of these could be reported as negative one day after the receipt of the sample. By the fermentation tube technique, because of the requirement for 48 hours incubation, only 59.5% of the samples could be reported as negative after *two days*. After another

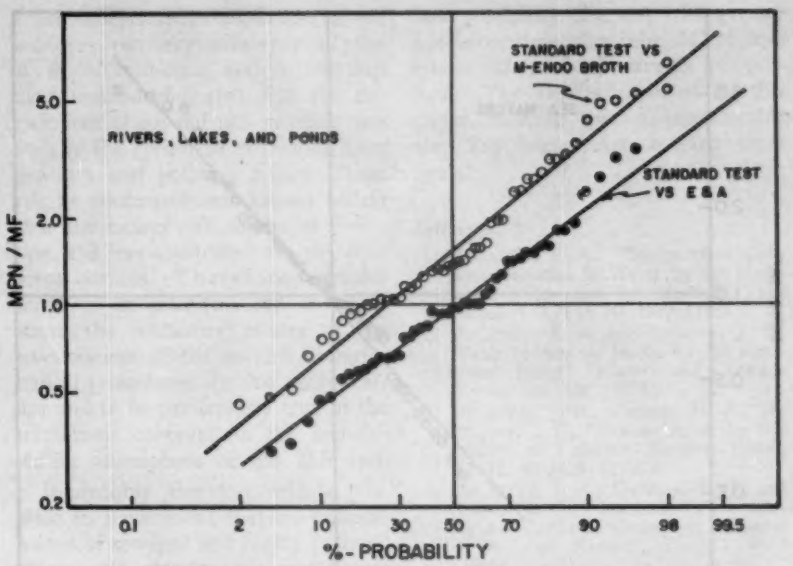

Fig. 1. COMPARISON OF standard multitube test against M-Endo broth membrane filter and against E & A membrane filter.

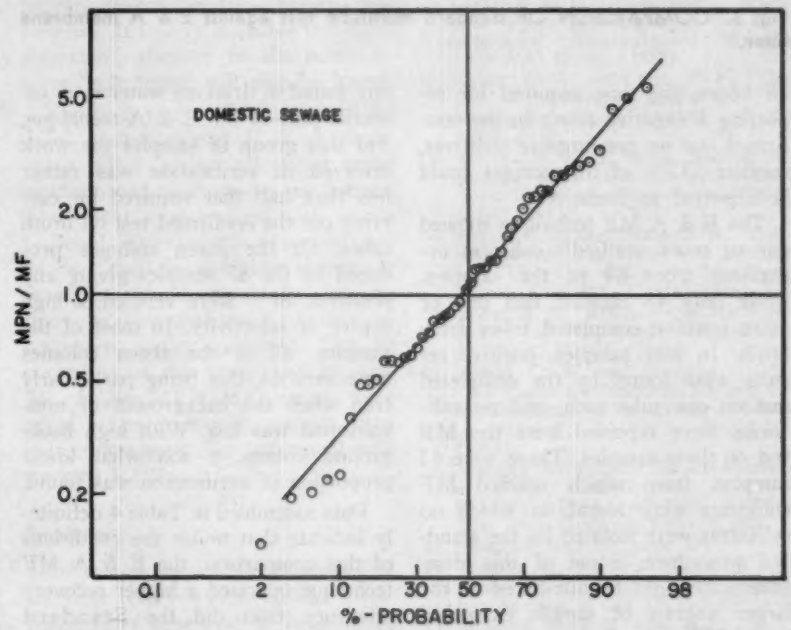

Fig. 2. COMPARISON OF standard multitube test against E & A membrane filter.

Table 4

Comparison of Standard Procedure and E & A Membrane Filter

	E & A Membrane Filter			Standard Fermentation Tube		
Total Number	Samples with no sheen colonies	Samples with one or more sheen colonies	False Positives	Samples with no Positive Presumptives	Samples with no Confirmed Positives	Samples with Completed Positives
654	567	87	3	389	220	45

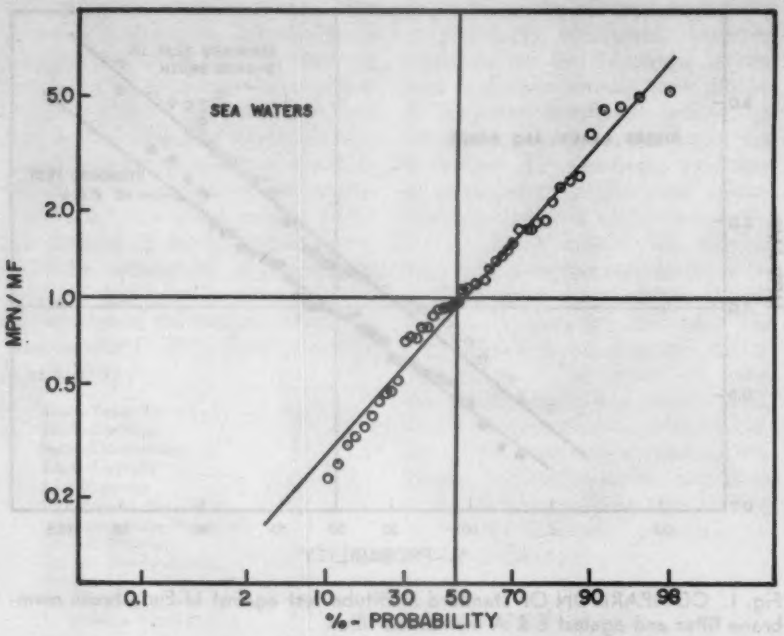

Fig. 3. COMPARISON OF standard multitube test against E & A membrane filter.

48 hours, the time required for reporting a negative result in the confirmed test on presumptive positives, another 33.7% of the samples could be reported as negative.

The E & A MF technique showed one or more verified[15] coliform organisms from 84 of the samples, while only 45 samples had one or more positive completed tubes from broth. In four samples, positive results were found by the completed test on one tube each, and no coliforms were reported from the MF test on these samples. There were 43 samples, from which verified MF coliforms were found, in which no coliforms were isolated by the standard procedure. Some of this disagreement might be attributed to the larger volume of sample examined by the MF test.

On the 87 samples from which positive MF tests were found, only three were shown in which all the sheen colonies failed to verify. By comparison, of the 3270 total tubes inoculated from the samples, 522 positive lactose tubes failed to confirm. In other words, about 16% of all the tubes inoculated were processed through the confirmation test without any positive coliform results. This is a rather important picture of the excess work which the standard method may involve.

The verification of each sheen colony found in drinking water is an essential part of the E & A technique. For this group of samples the work involved in verification was rather less than half that required for carrying out the confirmed test on broth tubes. Of the sheen colonies produced by the 87 samples giving any positives, 87% were verified, a high degree of selectivity. In most of the samples, all of the sheen colonies were verified, this being particularly true when the background of non-coliforms was low. With high background counts, a somewhat lower proportion of verification was found.

Data assembled in Table 4 definitely indicate that under the conditions of this comparison, the E & A MF technique operated a higher recovery efficiency than did the Standard Lactose Broth test. Even if the effect of the larger volume is discounted, it appears that the E & A technique finds larger numbers of coliforms than the Standard Procedure in waters of drinking quality. Many observers have, from time to time, reported that the Standard Procedure recovers only a part of all the coliforms present. For example, much larger coliform recovery has been reported from the droplet method.

It appears that this E & A test, which includes only slight alterations in medium and technique, may produce greater coliform recovery in many samples than the standard multitube procedure, rather than the smaller recovery generally reported with earlier techniques. The significance of the higher numbers still must be determined.

Additional Information from the Membrane Filter

Although the greatest usefulness of the membrane filter technique in water bacteriology at present is the enumeration of the coliform population, much added information in regard to other bacterial flora is available. Very seldom does an incubated filter show only coliform. Non-coliform organisms may be very significant. In swimming pool samples, for instance, the total count will furnish valuable information as to the sanitation of the pool, even if coliforms are few or absent. Certainly in the examination of a drinking water, it would be highly significant to find several hundred organisms resulting from the filtration of only perhaps 100 ml of tap water. Already it has been shown that the presence of considerable numbers of non-coliforms may foretell the later presence of the indicator organisms. The fermentation tube gives practically no such information, since gas production is the only important indication observed, and the turbidity which may appear after 24 or 48 hours of incubation gives little information of the original bacterial density of the sample, nor does it call the attention of the bacteriologist to possible approaching difficulties. The membrane filter, on the other hand, gives an estimate of the coliforms present, and as a bonus, also gives an estimate of other bacteria growing under the conditions presented.

This function of the membrane filter has not received much comment, but we believe it may prove meaningful in the bacteriological analysis of drinking waters. As stated above, high non-coliform counts may presage later appearance of the indicators. And it appears logical, even if coliforms are not shown, that a significant number of non-coliforms may indicate a "dirty" water, undesirable from the esthetic standpoint, at least, and demanding that steps be taken to produce a water free of non-coliforms as well as coliforms.

Polluted Waters

The results obtained by the E & A membrane filter method on waters not of drinking water quality are reported in graphical form in Figures 1, 2, and 3.

Figure 1 represents the analyses of 49 river, pond and lake samples that were examined by the E & A, one step M-Endo broth and the 5-5-5 multitube techniques. The ratios of the MPN to E & A and the MPN to M-Endo broth (one-step) results were calculated and arrayed in order of magnitude. The two sets of data were then plotted on log probability paper. The two lines of best fit show the difference in response produced by the two membrane filter methods.

Of the 49 ratios $(\frac{\text{MPN}}{\text{MF}})$ calculated from the one-step membrane filter method, 39 equal to, or greater than unity, while the MPN/E & A array showed that 23 ratios were equal to, or greater than unity. This comparison shows that the one-step membrane filter method using M-Endo broth as usual tends to give lower results than the MPN procedure. The E & A membrane filter analysis of waters of these types gives results practically equal to those from the tube method. The median ratio, or 50 percentile ratio, for the MPN/one step MF is 1.53 while the MPN/E & A MF is 0.97.

Figure 2 represents the analyses of 49 raw, settled and biologically treated sewage samples by the 5-5-5 multitube method and by the E & A membrane filter method. The ratios of MPN to E & A coliform densities were calculated, arrayed and plotted on log probability paper. The median or 50 percentile ratio of the 49 ratios is 1.10, with 26 ratios equal to, or greater than unity.

An independent comparison of the coliform recovery efficiency of the E & A technique and a one-step agar method indicated that the enrichment phase did not increase materially the coliforms recovered from sewages and polluted rivers. These results confirmed well-known beliefs that the nearer the source of pollution, the less attenuated are the coliform strains. Therefore, smaller numbers of coliforms fail to withstand the inhibitory effects of the environment of the various bacteriological procedures. In this study, this appears to be particularly true of the inhibitions observed in the fuchsin-sulfite atmosphere of the MF test.

It probably, therefore, will be possible to recommend that on examinations of sewages and highly polluted rivers and streams the enrichment stage of the E & A membrane technique may be omitted without significant effect on the coliform recoveries. It is very probable that considerable reduction in the non-coliform background will also be found.

Figure 3 presents the array of 49 3-3-3 multitube and E & A membrane filter ratios calculated from simultaneous analyses on sea waters. The filters were washed with sterile buffered water in the same manner as that used in drinking waters. It was not found necessary to use three to five additional washes as had been earlier indicated. The 50 percentile of the array is 0.96, and 24 of the MPN/MF ratios were equal to, or greater than unity, thus indicating a very close agreement with the tube MPN.

Summary

In our paper on the reliability of coliform tests[3], we stated the membrane filter appeared to possess the best possibility of a test with greater precision than the tube MPN and enumeration of all strains of coliform. The results reported in this paper indicate that a considerable step has been taken toward these goals.

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Water sampling and comparative analysis for Coliforms permit a critical examination of the . . .

Multiple-tube Dilution and Membrane Filter Methods

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EDITOR'S NOTE: The Eleventh Edition of *Standard Methods* provides water and wastewater technicians with a dual standard applicable to coliform organism detection and enumeration. The standard as written was accepted only after considerable discussion and with reservation by some. Data are presented here which ought to stimulate discussion among analysts. Further research must be encouraged and aimed at evolving techniques by means of which sampling and parallel analysis using the two methods would yield comparative results. A Research Progress Report on this subject appeared in the June 1961 issue of WATER & SEWAGE WORKS.

■ THE MEMBRANE FILTER technique (MF) for enumerating coliform organisms in water has been widely tested over the past ten years since the original report by Goetz and Tsunneishi[1] in 1951. The technique has a number of advantages over the multiple-tube dilution (MTD) method which has been standard procedure for testing water throughout the world. The principal advantage of the MF technique is the testing of waters with low coliform organism content (less than 2 per 100 ml). It also has all the advantages of the pour-plate technique which has been a standard procedure for enumerating bacterial populations in milk and foods.

By the use of diagnostic media, such as Endo's medium, the MF technique has made possible a direct count of coliform organisms in water by using large volumes of water for low populations or by dilution procedure for high populations.

The eleventh edition of *Standard Methods for the Examination of Water and Waste Water*[2] states that either the MTD or MF techniques may be used for the enumeration of coliform organisms in water within the limitations specified for each technique. No limitations are placed on either procedure for the examination of potable waters.

Where two methods are included in standard procedures, the Committees responsible for the preparation of the standard procedures must be sure that the results from both tests are equivalent; otherwise, two methods might be in use throughout the country, yielding data not in conformance. Inasmuch as the standard method for enumerating coliform organisms is designed to measure the public health hazard of water, it is essential and mandatory that the sensitivity of the two methods be the same in all waters used for human consumption; either raw water from a protected water shed, or treated water originating from a sewage contaminated source.

Unfortunately, not all members of the American Public Health Association Committee responsible for the preparation of bacteriological standards are in agreement that these two procedures yield comparable results. The senior author, (a member of the above committee) believes that the MF technique does not yield data comparable to the MTD procedure and that further research is necessary to improve the sensitivity of the technique. The authors believe that the sensitivity of the MF technique is particularly poor when testing marginal waters, i.e. waters considered in the potable area. This paper is a presentation of data gathered over the past five years in an extensive study of the MTD and MF techniques.

These studies were initiated as the result of the development of the drop-plate technique for the enumeration of coliform organisms[3] by the writers. The drop-plate technique was developed as a companion procedure to the MF test. The latter test for waters of low coliform population and the former for high coliform populations where dilution of the sample would be necessary for application of MF tests.

Technique Evaluation

To evaluate the drop-plate technique, comparative tests were made by the MTD procedure employing lauryl tryptose broth, using sewage effluents and river waters. In an examination of sewage effluent, 14 tests

Table I

Comparison of Three Methods for the Quantitative Determination of Coliform Organisms in a Sewage Contaminated River.

Sample No.	Coliforms per 100 ml of sample: Drop Plate	MTD	MF
	(10 replicates)**	(5 replicates)*	(10 replicates)**
1	15,200	10,250	10,200
2	9,500	8,170	3,125
3	9,860	9,200	6,900
4	10,800	12,000	7,750
5	9,450	7,100	8,625
6	6,700	4,580	3,930
Geom. Mean Av.	9,730[1]	8,250[2]	6,640[3]

*Each trial consisted of 3 dilutions of 5 tubes each.
**M Endo MF (Difco) used for drop plates and MF tests.
1—Drop plate average represents 250 0.04 ml counts.
2—MTD averages represents 25 5 tube replicate plantings in 3 dilutions.
3—MF averages represent 60 0.02 ml counts.

were made using 9 drop-plate counts for each (126 replicates) and 14 sets of 5 tubes in each of 3 dilutions (70 replicates). The geometric mean was 1,700,000 organisms/100 ml for the drop-plate technique and 920,000 organisms/100 ml for the MDT test. The drop plate technique gave a coliform count (confirmed) 1.84 times greater than that for the MTD procedure. In every set of data gathered, the drop-plate technique gave much higher counts than did the MTD procedure, demonstrating that by laboratory testing, the MTD calculated by either arithmetic or geometric means was less than the actual number of coliform organisms present. The application of a bias correction factor to reduce the MPN's to a true index as reported by Thomas, Woodward and Kabler[4] is unwarranted as the true coliform content of water is considerably higher than the presently reported MPN's.

McCarthy, Thomas and Delaney[5] found in a pure culture study using coliform organisms that the MTD geometric mean was 10% higher than agar pour-plate counts. It has been the authors' experience that pure cultures of coliform organisms in the logarithmic stage of growth always yield higher indices in liquid media than do coliforms found in water that may be in their stationary growth phase. In drop-plate studies, pure cultures gave a 1 to 1 ratio for drop-plates and MTD methods.

The writers have observed over a period of years that the MF technique yields a lower coliform count than that obtained by MTD procedures. This lower count was believed to be due to improper media, so studies were made by McCarthy[6] with some degree of success. Others, such as Hajna and Damon[7] and Fifield and Schaufus[8], McCarthy and Delaney[9] Noble and Reitman[10], Clark, *et al*[11] have proposed media that have yielded greater recovery of coliform organisms. In the hands of the authors, the M Endo MF medium reported by Fifield and Schaufus[8] has been the best to date.

Comparative Studies

A comparative test of media was made with the drop-plate procedure by placing a known amount of contaminated water (.02 ml) on M Endo MF agar and an equal amount on the surface of a membrane filter placed on the surface of M Endo MF agar. Considerable difficulty was encountered in spreading the water over the surface of the membrane. However, after numerous trials, it was found that the number of colonies was approximately the same on the two different surfaces. This would indicate that the drop-plate technique and the membrane filter procedure should yield similar results and that media were not responsible for the lower counts observed in routine use.

Table 1 presents data on a comparative study of the drop-plate, the MTD and the MF techniques. Six samples from the same source were tested. Each sample was replicated 10 times on the drop-plates and membrane filters and the MTD consisted of 6 replicates of 3 dilutions of 5 tubes each. The relationship of the three methods is presented as the geometric mean as follows: the count on the drop-plates was 9730 organisms/100 ml, the MTD 8250 organisms/100 ml and the MF 6640 organisms/100 ml. The water source was a sewage-contaminated river. The averages represent 60 drop-plate counts, 60 membrane filters and 30 replicate tubes in the MTD tests, so experimental error is reduced materially.

These data indicate that in sampling a sewage contaminated river water the drop-plate yielded the highest coliform organism count. The MTD technique count was 1.24 times greater than that for the MF procedure.

The coliform counts that were approximately 25 percent lower on the MF than the MTD were of great interest. As previously stated about the same counts were obtained by the drop-plate technique on agar and the membrane filters. It could be that the filtration process was responsible for lowering the counts. Accordingly, a series of tests was run where the amount of water filtered was the only variable. In the first series, 0.2 ml of sewage-contaminated river water was planted by the drop-plate method on M Endo-MF (Difco) agar. Secondly, 0.2 ml of sample was filtered through a membrane filter (replicated 9 times) and the membrane placed on M Endo-MF (Difco) agar.

In a third series, 9 membrane filters were seeded with 0.2 ml followed by a 5 ml wash of sterile buffered dilution water. In a fourth series, 9 membranes were seeded with 0.2 ml followed by 100 ml of sterile buffered dilution water and in a fifth series the 0.2 ml was followed by 200 ml sterile buffered dilution water.

The counts for the various series of tests are reported in Table 2. The drop-plate counts gave a geometric mean of 27.1 colonies and the MF receiving only 0.2 ml yielded 22.4 showing that the filtering action on 0.2 ml did not produce a significant reduction in colony numbers. When 5 ml sterile buffered water followed the 0.2 ml inoculum, the geometric mean count was 20.2 and when the 0.2 ml inoculum was followed by 100 ml and 200 ml the mean counts were 13.2 and 12.8. The passing of volumes of 100 and 200 ml of water resulted in a lower coliform count, although the inoculum was constant. The values showed that counts with

Table 2

The Effect of Volume Filtered on the Number of Coliform Organisms Detected by the Membrane Filter Technique Using 0.2 ml of Sewage Contaminated River Water.

Trial	Coliforms per 0.2 ml of sample*				
	Drop Plate	Membrane Filter Technique			
	Amount of Sample + buffered dilution water				
	0.2	0.2	0.2 + 5	0.2 + 100	0.2 + 200
1	28	27	27	3	4
2	30	20	27	5	6
3	31	18	25	1	14
4	25	18	22	21	11
5	25	33	33	34	22
6	23	42	27	6	25
7	28	25	30	28	27
8	28	39	22	22	21
9	27	29	20	36	19
10		32	25	22	21
11		14	6	16	16
12		19	15	24	12
13		12	9	18	11
14		22	18	21	4
15		12	22	17	4
Geom. Mean	27.1	22.4	20.2	13.2	12.8
Percent reductions		17.4	25.5	51.3	52.8

*Medium used—M Endo MF (Difco).

the 100 and 200 ml filtration were significantly smaller than the control.

This experiment has been repeated a number of times and each time a marked reduction occurred when 100 ml and 200 ml of water were used.

These data demonstrate that large volumes of water passed through the filter over the coliform organisms trapped on the filter tended to reduce colony counts. This may be due to damage to some cells, thus stopping reproduction. In a later paper, data will be presented which will show this to be true.

When selective agents, such as bile salts, brilliant green, fuchsin, etc. are added to a medium to prevent the growth of gram positive bacteria, the amounts needed have a slight inhibitory action on the gram negative organisms as well. Many media such as brilliant green bile broth, oxbile broth, 0.1 percent phenol broth, fuchsin broth, and crystal violet broth were designed originally for the primary growth of coliforms from water. However, upon testing for this purpose, they were found inhibitory to some coliform organisms and were then used as confirmatory media, where organisms in their logarithmic growth phase could withstand the inhibitors. Only one of these media is recognized by *Standard Methods*, namely brilliant green bile broth and in this medium a large inoculum must be used to assure growth of the coliform organisms.

The viable coliform cells in water vary in their ability to reproduce depending upon the environment. Organisms in sewage reproduce readily because they are only shortly removed from their logarithmic growth phase. Coliform organisms in ground water acquifers and in rivers and lakes may be in the stationary phase of their growth cycle so considerable time may elapse after being placed in a nutrient medium before reproduction starts and if the medium is not fully adequate for growth, or inhibitory substances are present, reproduction may never occur.

An ideal medium would be one that makes possible the growth of viable coliform organisms present irrespective of their degree of viability. Such a medium would yield 100 percent of the viable coliform organisms present in swimming pools and finished waters where chlorine may have only injured the cells, in ground water acquifers where low temperatures may have reduced viability, and in sewage where organisms are only shortly removed from their growth phase. As far as the authors are concerned, no such medium exists. In comparisons of lauryl tryptose broth and lactose broth, McCrady[12] reported that lauryl tryptose broth was only slightly better than lactose broth in sewage contaminated waters, but in swimming pool waters 13 percent, in wells and springs, 17 percent, in sea water 25 percent, and in miscellaneous waters in the marginal classification 37 percent better in the detection of coliform organisms.

The senior author observed in a study of lauryl tryptose broth and lactose broth on finished water that coliform organisms were always detected first in the lauryl tryptose broth and sometimes only in lauryl tryptose broth. In water plant operation, lauryl tryptose broth would be the medium of choice for finished waters and waters in the various stages of treatment for this reason.

The medium used in the membrane filter technique contains inhibitory agents and filtering of large amounts of water appears to reduce the number of culturable coliform organisms. Because of this, samples of various types of water were tested. 25 replicate tubes in 3 dilutions for the MTD and 5 membrane filters were analyzed in appropriate amounts, depending upon the coliform density of the sample, to determine the constancy in

Table 3

A Comparison of the Coliform Indices Obtained by the MTD and MF Methods Using Sewage Contaminated Water from a River.

Sample No.	Coliform Indices		Ratio MF:MTD
	MF*	MTD**	
1	3,700	29,700	1:8
2	9,500	19,300	1:2.03
3	13,000	14,600	1:1.2
4	12,400	12,400	1:1
5	12,000	4,400	1:0.36
6	10,800	12,200	1:1.13
7	9,600	9,200	1:0.96
8	13,600	9,000	1:0.66
9	30,700	35,000	1:1.14
Geom. mean	11,300	15,100	1:1.3

*5 trials of each dilution—M Endo MF Medium (Difco).
**5 trials of 3 decimal dilutions of 5 tubes each—lauryl tryptose broth (Difco).

detecting culturable coliform organisms.

Table 3 presents test results of a sewage contaminated river on different days. With the exception of one sample the counts obtained by both methods are in fair agreement. These results would be anticipated as the coliform organisms encountered represent relatively fresh contamination of the river at the collection point.

Table 4 presents the results from 4 deep wells that were known to be contaminated. The ratios varied from 1 to 5.4 to 1 to 1.04 in favor of the MTD procedure. Well No. 3 was badly contaminated and the ratios for the two samples tested were 1 to 1.04 and 1 to 1.18. Also in Table 4 are presented data on three samples from a shallow well. The contamination was largely *Aerobacter aerogenes* and probably was caused by the use of priming water of questionable quality. The counts obtained by the MTD procedure were approximately double that for the MF technique. The contamination was high, but the organisms were likely in the stationary growth phase.

In Table 5 the data represent samples collected from rivers and lakes. The first river travels through sparsely settled areas and no municipal sewage enters above the point of sampling. The water is clear and no deposit occurred on the filters when 100 ml amounts of water were filtered. The ratios vary from 1 to 146 to 1 to 5.4. Although the coliform organisms were high in number, the MF failed to cultivate them. The second river carries no municipal sewage above the point of collection but travels through an agricultural area. The ratios here were 1 to 9.4 and 1 to 9.8. Again, although the coliform population was high the MF technique failed to detect them.

The first lake at the point of collection was heavily contaminated by bathers. The ratio was 1 to 7.4. This lake is biologically active so the MF technique may not have functioned because of other bacteria that were present. The second lake is biologically active with no sewage contamination. Ratios of 1 to 81.8 and 1 to 32 were obtained. Again the MF technique failed to detect culturable coliform organisms.

Table 4

A Comparison of the Coliform Indices Obtained by the MTD and MF Methods Using Water from Contaminated Wells.

Well No.	Coliform Indices MF*	MTD**	Ratio MF:MTD
	Deep Wells		
1	44	240	1:5.4
2	7	16	1:2.2
3(a)	101	106	1:1.04
(b)	844	996	1:1.18
4	108	193	1:1.78
	Shallow Well		
5(a)	2,350	4,900	1:2.08
5(b)	2,600	4,370	1:1.68
5(c)	2,060	6,160	1:2.99

*5 trials of each dilution—M Endo MF Medium (Difco).
**5 trials of 3 decimal dilution of 5 tubes each—lauryl tryptose broth (Difco).

Table 5

A Comparison of the Coliform Indices Obtained by the MTD and MF Methods Using Surface Waters.

Sample No.	Coliform Indices MF*	MTD**	Ratio MF:MTD
	River (relatively clean)		
1	12	1,760	1:146
2	16	489	1: 30.5
3	54	295	1: 5.4
	River (agricultural pollution)		
4	408	3,840	1: 9.4
5	638	6,250	1: 9.8
	Lake (contaminated)		
6	64	477	1: 7.4
	Lake (uncontaminated)		
7	22	1,800	1: 81.8
8	40	1,280	1: 32

*Trials of each dilution—M Endo MF Medium (Difco).
**Trials of 3 decimal dilutions of 5 tubes each—lauryl tryptose broth (Difco).

Table 6

A Comparison of the Coliform Indices Obtained by the MTD and MF Methods Using Lake Michigan Water from the Intake at Water Treatment Plant No. 1.

Sample No.	Coliform Indices MF*	MTD**	Ratio MF:MTD.
1	0.4	10.6	1:26.
2	0	0.4	—
3	2.2	26.8	1:12.
4	0.4	9.6	1:24
5	0.36	11.2	1:31
6	0	0	—
7	2	7	1: 3.5
8	26.	24.4	1: 0.93
9	0	46.5	—
10	1.2	4.16	1: 3.5
11	1.5	8.57	1: 5.7

*5 Trials of each dilution—M Endo MF Medium (Difco).
**5 Trials of 3 decimal dilutions of 5 tubes each—lauryl tryptose broth (Difco).

Great Lakes Water

Five raw water samples from five water purification plants obtaining water from the Great Lakes were selected for testing. These waters were selected because they are the nearest in coliform population to an acceptable potable water available and they represent the types of waters for which the MF technique is especially suitable. If the technique failed to detect culturable coliform organisms from these waters then obviously failure would be true for finished waters where the probability of finding coliform organisms is low.

In Table 6 are presented data for a city receiving lake water of relatively good quality. Eleven samples were collected at the plant on different days.

There is no need for a statistical analysis of the data, as the differences are markedly in favor of the MTD procedure. Remembering that the 95 percent confidence limits for 25 replicates would be approximately 45 percent for the lower limit to 65 percent for the upper limit (13), only one sample, No. 10, would be in agreement.

In Table 7 are presented data from a city water supply from the same lake, but showing considerably more contamination. Although the ratios are closer than in the water reported in Table 6, in only one instance is there agreement between the two methods.

In Table 8 data are presented for a city water supply from another

Table 7

A Comparison of the Coliform Indices Obtained by the MTD and MF Methods Using Lake Michigan Water from the Intake at Water Treatment Plant No. 2.

Sample No.	Coliform Indices MF*	MTD**	Ratio MF:MTD
1	5	30.4	1:6
2	2.2	17.4	1:7.9
3	9.	26.9	1:3
4	96	138	1:1.4
5	69	619	1:8.9

*5 Trials of 100 ml each—M Endo MF (Difco).
**5 Trials of a 3 decimal dilution of 5 tubes each—lauryl tryptose broth (Difco).

lake. The raw water from this plant generally shows greater coliform indices than those reported in Tables 6 and 7. Ratios can be reported on only three samples, 1 to 3.3, 1 to 18.7 and 1 to 16. In the other two samples, no coliform organisms were detected in 500 ml of sample by the MF technique, whereas the MPNs were 97.8 and 26.6. The MF technique failed to detect culturable coliform organisms. No agreement was obtained on any samples.

In Table 9 are presented data on another city water supply from the same lake as that reported in Table 8. This raw water gives variable numbers of coliform organisms due to sewage effluent in the area. Agreement occurred between two samples, one with high coliform and the other with low coliform populations. No culturable coliform organisms were detected in two samples using the MF technique.

Table 8

A Comparison of the Coliform Indices Obtained by the MTD and MF Methods Using Lake Huron Water from the Intake at Water Treatment Plant No. 3.

Sample No.	Coliform Indices MF*	MTD**	Ratio MF:MTD
1	0	97.8	—
2	0	26.6	—
3	70	234.	1: 3.3
4	8	130.	1:16
5	10	187.	1:18.7

*5 Trials of 100 ml each M Endo MF—(Difco).
**5 Trials of a 3 decimal dilution of 5 tubes each—lauryl tryptose broth (Difco).

In Table 10, data are presented from a water supply source that seldom shows coliform organisms by the MTD tests. Coliforms were detected in two samples by the MTD test whereas no culturable coliforms were obtained using 500 ml of water by the MF technique.

These data (Tables 3 to 10 inclusive) demonstrated that where coliforms of recent fecal origin were present, the MTD and MF tests gave comparable results although the MF counts are in the lower bracket of 95 percent confidence limits. When coliforms were apparently in their stationary phases, characteristic of marginal waters, the MF technique, as presently performed according to *Standard Methods for the Examination of Water and Waste-Water,* 11th Ed. failed to yield many of the culturable coliform organisms and yielded results not comparable to those obtained using lauryl tryptose broth in the MTD test.

Table 9

A Comparison of the Coliform Indices Obtained by the MTD and MF Methods Using Lake Huron Water from the Intake at Water Treatment Plant No. 4.

Sample No.	Coliform Indices MF*	MTD**	Ratio of MF:MTD
1	0	4.4	—
2	0	4.7	—
3	678***	764	1:1.1
4	2	16.5	1:8.2
5	5.2	6.7	1:1.3

*5 Trials of 100 ml each—M Endo MF (Difco).
**5 Trials of a 3 decimal dilution of 5 tubes each—lauryl tryptose broth (Difco).
***Appropriate dilutions used.

On the waters examined in this study, Standard Methods provided two standards, one more sensitive than the other.

If a standard of sanitary quality is to be maintained of not more than one coliform per 100 ml of water, then when alternate methods are offered, the results from these methods should be similar.

Other Reports

The results presented in this report are not different from those presented by others, if the data are treated the same as those in this report. Kabler[14] in 1954 reported on a survey made by a committee on the comparative results obtained by testing various waters with the MTD procedure using 5 replicates of each dilution and membrane filters. The results were reported on the basis of 95 percent confidence agreement or disagreement. Many samples wherein no coliforms were detected with either method were reported and included in the summation of the data. These samples, which yielded no information on the comparative value of the two methods constituted approximately 25 percent of the samples.* These samples are reported as in "negative agreement" and are included as showing that the two methods are in agreement. If these samples are excluded, instead of an agreement of 74 percent, the agreement becomes 60 percent. In a group of samples collected from waters in the potable category, 650 samples were reported. In this group there were 114 listed as ± agreement, 457 negative agreement and 79 in disagreement. By adding the ± and negative agreements together, 88 percent were in agreement. However, if the 457 negative agreements are discarded as showing nothing in regards to the merits of the two methods in detecting coliforms, the agreement is only 58 percent. The agreements of 60 percent for the first group and 58 percent for the second group show that the two methods are different in their sensitivity, and that the MF technique only detects part of the culturable coliform organisms present in the water. The author states "These results indicate that the two test procedures do not measure precisely the same group of organisms and that the sanitary significance of the differences in results of the procedures is yet to be determined."

*Facetiously, if one method used a medium containing a germicide, and no coliforms were present in the waters in the quantities tested, both tests would yield negative results. Certainly the two methods would not be in agreement in detecting coliform organisms. To make a comparison of two techniques, there must be something to compare.

Table 10

A Comparison of the Coliform Indices Obtained by the MTD and MF Methods Using Water Taken from a Ranney Collection System in Lake Michigan Water Treatment Plant No. 5.

Sample No.	Coliform Indices MF*	MTD**	Ratio of MF:MTD
1	0	0	—
2	0	0.8	—
3	0	0	—
4	0	0.4	—
5	0	0	—

*5 Trials of 100 ml each—M Endo MF (Difco).
**5 Trials of a 3 decimal dilution of 5 tubes each—lauryl tryptose broth (Difco).

Conner[15] in an examination of sea water presented three tables of data for three different sampling locations. The MTD values were calculated from a three tube replicate dilution procedure. The MF tests were made on EHC and BGF media; and the latter gave the highest coliform organism counts. An arithmetic average was taken of each set of data for both MTD and MF techniques.

The average MPN was adjusted for a positive bias of 43 percent and confidence limits for a 3 tube test were 0.21 to 3.95. An agreement of 89 percent was obtained.

These writers present the data from the three tables in graphic form (Graphs 1, 2 and 3) arranging the samples in descending order for the MPN values. The 95 percent confidence limits are indicated by shaded area. It will be observed that although nearly all the MF counts are within the 95 percent confidence limits of the MPN values, they are, without exception, in all three graphs on the borderline of the lower confidence limits indicating a lower population level. The ratios of the MF counts to the MPN value based on the geometric means are 1:1.3 for graph 1 and 1:2.6 for graphs 2 and 3

Presnell, Arcisz and Kelly[16] presented MF counts and MTD values on sea water from three stations. They report that the percentage agreement for the two methods was higher for waters of high coliform populations than for waters of low or moderate coliform populations. A comparison of the geometric means for each table showed a ratio for Station C (high coliform populations) for the MF to the MTD of 1:0.9, for Station A (low coliform populations) 1:1.6 and Station B moderate coliform populations 1:2. With the exception of Station C, the MF counts are close to the lower 95 percent confidence limits, indicating in general a lower count of culturable coliform cells.

Adams[17] in a comparative study of MF and MTD tests reported on 315 samples of prechlorinated Allegheny River Water. He reported 88.4 percent agreement by including 129 tests where both tests yielded negative results, giving no comparative data on the value of the tests in detecting culturable coliform organisms. If these are excluded, his percentage agreement drops to 56 which would indicate the results of the two tests were not the same. With raw waters having high coliform populations, the two methods gave approximately the same results, with ratios ranging from 1:1.02 to 1:0.884.

Summary

Data have been presented to show that the coliform indices of marginal and potable waters obtained by the MF technique are not comparable to those obtained by the MTD method. This creates a dual standard for potability if a coliform index of 1.0 is used.

Comparable results are obtained when organisms are in or near the logarithmic growth phase. However, more study is indicated to improve the media and techniques used with the membrane filter, to secure a more accurate enumeration of the culturable organisms present in relatively good waters, where the coliform organisms are generally in the stationary phase of growth.

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ORP limitations in . . .

Activated Sludge Process Control

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■ THE UTILIZATION of oxidation-reduction potential measurements as a parameter during sewage treatment is not a new idea; neither is the theory and measurement of ORP a recent development. Rohlich, et al, 1941, published the first significant study of the relationship of ORP measurement to sewage treatment control [20]. Numerous articles have since appeared: Eckenfelder & Hood [3 4]; Eliassen [5]; Grune & Chueh [7]; Gruen & Lotze [8]; Hood [10]; Hood & Rohlich [11]; Keefer & Meisel [13 14 15]; Kehoe & Jones [17]; Moore, et al [18]; Nussberger [19]; Rohlich [21 22]; and Shapiro [23].

In order to gain more basic information and a better insight into the activated sludge process and to more effectively control that process at this plant, it was decided to investigate the possibility of study and control of the process by oxidation-reduction potential measurement methods. Following an intensive study of the literature, it was decided to utilize the method advanced by Nussberger [19]. It was felt that the classic tests; i.e., settleable solids, suspended solids, volatile solids, dissolved oxygen, biochemical oxygen demand, nitrate, nitrite, and nitrogen determinations, were not providing the type of information necessary to fully evaluate the process. Further, it appeared that the ORP method offered a much simplified means of process control.

The Nussberger Method

The method advocated by Nussberger, subsequently to be referred to as the *ORP Loss Curve Method,* involves the sealing of a grab sample of aerator effluent in a container together with a platinum and a calomel electrode and, while keeping the sample in suspension with the help of a magnetic stirrer, to take ORP readings at regular intervals, see Fig. 1. For this study the Beckman No. 39271 Platinum Thimble and No. 39170 Calomel electrodes were employed in conjunction with the Beckman Model G and Zeromatic pH meters. The Model G was quickly discarded for this use in favor of the Zeromatic. Since the meter was in such constant use, the battery operated Model G gave considerable difficulty due to weak batteries which lead to erroneous results and a considerable waste of time. The Zeromatic, on the other hand, being a line operated instrument, yielded, with only nominal care, quite reliable results. No difficulty was experienced with the electrodes used in this study.

When the various ORP readings are plotted, a curve is obtained which, according to Nussberger [19], can be characterized as *normal, overloaded, underaerated,* and so forth, see Fig. 2. It was apparent from the beginning that, taken at face value, each curve really contained several elements. For example, a curve might display elements of both overaeration and underloading. It has been concluded [19] that the slope of the curve thus obtained, or, to state it differently, the time it took the ORP level to reach zero, in hours T_z, must be related to the loading of the system, degree of aeration, etc.

Several hundred tests using the ORP Loss Curve Method were conducted at this plant and the curves plotted. An attempt was then made to correlate T_z with the usual parameters of loading such as lbs BOD/1000 cu ft of aerator, lbs BOD/100 lbs mixed liquor suspended solids (MLSS), and so on. No correlation was found, nor was a correlation found with the usual parameters of process efficiency such as per cent BOD removed or lbs BOD/day in the plant effluent.

Theoretically, the lower the value of T_z the higher the aerator loading as judged by some unit as lbs BOD/100 lb MLSS. If a loading of 30 lb BOD/100 lbs MLSS resulted in a T_z value of 1.50 hours, then a loading of 15 lb. BOD/100 lb MLSS should result in a T_z value of something like 3.00 hours. Theoretically, T_z is inversely proportional to the load applied to the aerator or activated sludge system, see Fig. 3. It is entirely possible and even quite probable that this is true when all other factors remain unchanged. Unfortunately, such ideal conditions are found only in rigidly controlled laboratory studies. In actual plant practice, the

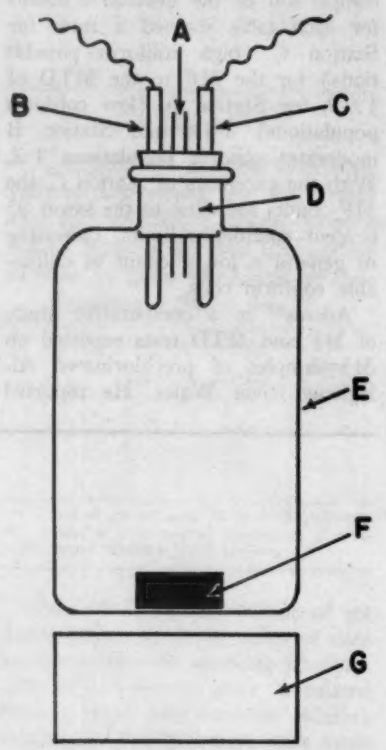

Fig. 1. APPARATUS for determining the ORP loss curve. A, glass tube; B, calomel electrode; C, platinum electrode; D, three-hole rubber stopper; E, one liter wide mouth bottle; F, magnetic bar and G, magnetic stirrer.

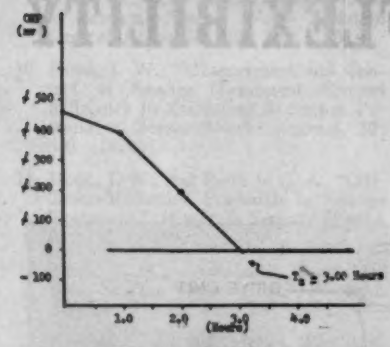

Fig. 2. TYPICAL ORP loss curve. Derivation of T_s from typical ORP loss curves.

composition of the influent raw sewage varies so widely that this factor alone is more than sufficient to invalidate most generalizations. It is elementary that raw sewage is a complex mixture of organic and inorganic substances. The presence of ions such as Cr + 6 in significant concentration in the raw sewage can have a most pronounced effect on the outcome of the ORP Curve Procedure and this is only one ion out of the entire range of possibilities, see Fig. 4. When viewed in this light, simple correlations were not found.

In one series of tests, which was typical of the entire study, a T_s of 1.75 was obtained with loadings of 3, 27, 34, & 53 lb BOD/100 lb MLSS, respectively. In another series, BOD removals of from 74 to 94 per cent were obtained with a T_s of 3.00. Table I gives some typical ranges encountered.

It is entirely possible that the ORP Loss Curve Procedure could be used to advantage at sewage treatment plants which receive only domestic wastes. Numerous papers have pointed out the possibility of using ORP precedures in the detection of industrial wastes and their treatment: Baffa[1]; Eckenfelder & Hood[4]; Greer[6]; Hood & Rohlich[11]; Keefer & Meisel[15]; Kennedy[16]; and Hoot[12]. Other papers have pointed out the effect of pH on ORP readings: Eckenfelder & Hood[3]; Henry[9]; Kehoe & Jones[17]; and Shapiro[20].

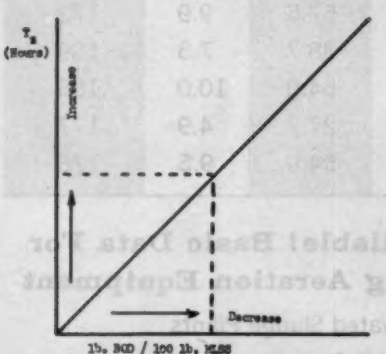

Fig. 3. THEORETICAL relationship of aerator loading to T_s.

Unless the pH of the plant influent remained fairly constant and the influent was free of industrial wastes, it is only to be expected that the usefulness of ORP procedures will be greatly limited, if not ruled out entirely, except as a means to detect such wastes. Sewage entering the treatment plant of the City of Warren contains a large amount of industrial waste. There are more than 600 industries within the city. Among these 600 industries are practically every type of plating operation. Although these industries are controlled and their wastes continuously monitored so that only minor amounts of cyanide and the heavy metals reach the treatment plant, their presence would appear to be a major cause of failure to correlate T_s with plant loading. It must be remembered that not only is it necessary to consider the effect of the heavy metals and the like, but also an infinite number of industrial chemical compounds that are in current use and find their way into the city's sewage system.

In use today is a seemingly endless array of cleaners, solvents, stripping compounds, anti-foam agents, wetting agents, flocculants, disinfectants, and the like. So pronounced are the effects of some of these and so sensitive are the ORP procedures available today, that methods such as the ORP Loss Curve Procedure have been used with some success at this plant to assess the effect of these various materials on activated sludge.

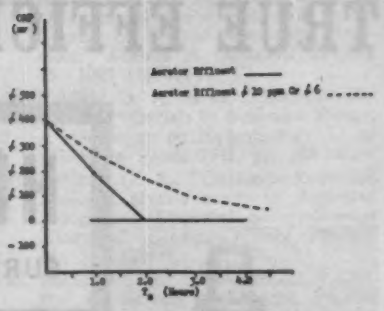

Fig. 4. EFFECT of hexavalent chromium on the outcome of the ORP loss curve procedure.

Summary

ORP test methods have been widely advocated for the study and control of waste treatment processes. The results of this study point up some of the limitations of these test methods. It has been shown that industrial wastes seriously limit the use of at least one ORP procedure. The rate at which the ORP level of aerator effluent falls to zero is theoretically inversely proportional to the loading of the present study, due probably to interference by industrial waste.

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Table I

Range of Aerator Loadings and Values of T_s Showing Lack of Correlation

T_s	Range lb BOD/100 lb MLSS
1.50	6 to 15
2.00	1 to 39
2.50	5 to 74
3.00	8 to 67
3.50	3 to 30
4.00	17 to 36
4.50	3 to 37
5.00	7 to 78

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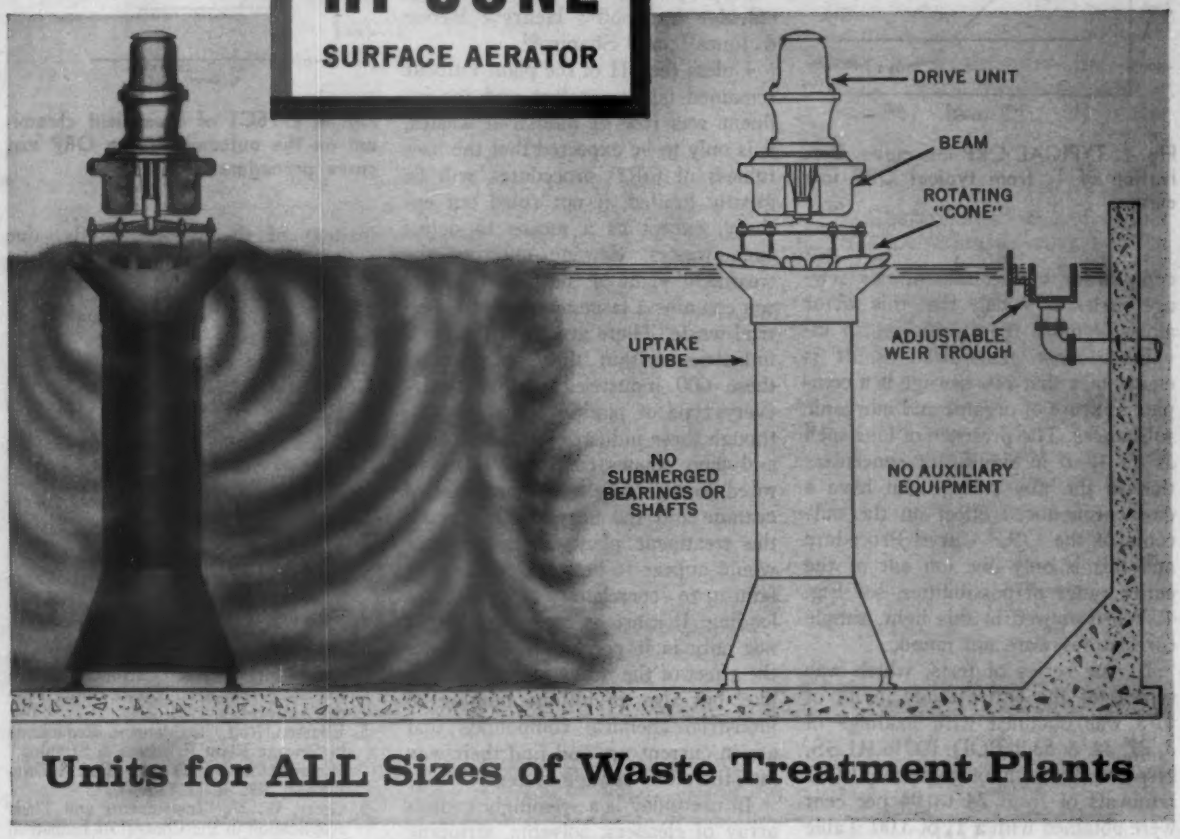

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½	34	37.2	7.0	.188
½	42	57.5	9.9	.172
2	38	38.7	7.3	.189
2	46	54.0	10.0	.185
4	34	27.7	4.9	.177
4	50	54.0	9.5	.176

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Gas Analysis by Chromatography

by W. L. HENDERSON, Research Analyst,
Orange County, Santa Ana, Calif.

EDITOR'S NOTE: Gas chromatography is a quick and reliable method for determining the quality of digester gas. The short 5 minute period required for complete gas analysis with this equipment could could make it a valuable tool in the control and operation of digestion processes of gas utilization facilities.

■ SINCE SLUDGE DIGESTION was first introduced as a major process in sewage and waste treatment there has been a search for better control tests. Initially, aside from observations of consistency, color and odor, the completeness of digestion was determined by analysis for fixed and volatile solids. pH measurements, made with color comparators after filtration or dilution of the sludge, were introduced in the late 1920's as an indication of the state of health of the digestion process. Still later methods of determining the concentration of organic acids, the "volatile acidity test", were introduced and generally found to be more sensitive to changes in the digestion process than the tests previously used.

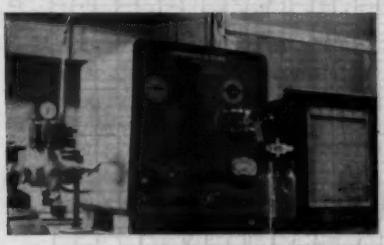

FIG. 1. GAS CHROMATOGRAPHY APPARATUS (L to R) Helium tank with pressure reducer and regulator, rotameter, chromatograph, and recorder. Sample is received from collection bottle through rubber tube at right side of chromatograph.

Most operators who have experienced trouble with sludge digestion have observed that a very early indication of trouble came through a change in the quantity or quality, or both, of the gas produced. Thus it has occurred to many that the analysis of the gas when compared with accurate records of gas production, provides a very sensitive control procedure. Unfortunately, the conventional methods for gas analysis by selective absorption and combustion apparatus has certain disadvantages. This apparatus is relatively complex and delicate, and requires a considerable degree of manipulative skill to operate. A complete analysis can require up to one hour. Finally, nitrogen is determined by difference, so that any and all errors will be in the nitrogen value.

Grune, Carter and Keenan, in 1956[1] described the use of a new method of gas analysis for following the progress of digestion in experimental digesters. This method, known as gas chromatography, is a relatively recent development, and provides an instrumental method for gas analysis. However, there seems to be very few applications of this method for routine digester control. Although the equipment is fairly costly, the time required for a complete gas analysis (nitrogen, methane, and carbon dioxide) is reduced to a matter of minutes. Other constituents appearing in small concentrations, such as hydrogen, ammonia, hydrogen sulphide, etc., can also be determined but are not so important in routine work.

Gas chromatography makes it practical to analyze samples of gas from a number of sludge digestion tanks daily. The time required for such gas

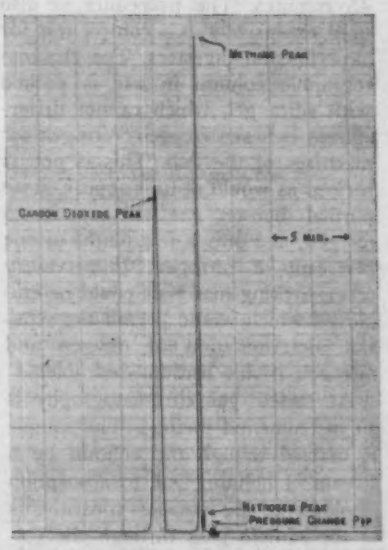

FIG. 2. RECORDED ANALYSIS of digester gas sample. The pressure dip (right) denotes introduction of the sample, then nitrogen came through, methane and finally carbon dioxide all in a matter of 3.5 minutes. The complete analysis should require no more than 4.5 minutes.

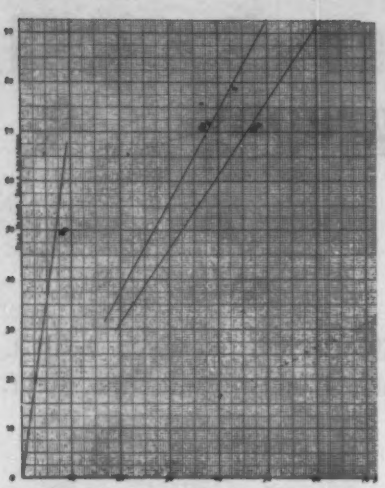

FIG. 3. CALIBRATION CURVE for gas chromatograph reflecting per cent concentration of nitrogen, carbon dioxide, and methane against peak height of curve for standard operating conditions.

analyses is less than for determinations of volatile acidity, and in addition there is no glassware to wash afterward.

This method of gas analysis has been in use in the laboratory of the County Sanitation Districts of Orange County, California, for about one year. The time required for the analysis of 7 samples per day is about 45 minutes. The procedure is also used extensively as a control test for experimental digesters. The chromatographic column in use is packed with silica gel, which cannot differentiate between oxygen, nitrogen, or mixtures of the two. This is not as serious as would at first appear, since normal digester gas will contain no oxygen, and only a few tenths of one per cent of nitrogen. If necessary other packing materials could be employed which would permit the separate determination of oxygen and nitrogen if this became desirable.

As stated, gas chromatography is an instrumental method. The sample is carried though the column by a stream of helium. Due to absorption phenomena, the various constituents of the sample pass through the column at different rates, and hence appear separately in the column effluent. At the end of the column the mixture of constituent and carrier gas pass through a thermal conductivity detector and produce electrical signals. These signals actuate a strip chart recorder, giving peaks for the various constituents. Figure 2 is a reproduction of the actual recorded trace from an analysis of digester gas. When quantitative results are desired, a calibration chart can be developed by plotting peak height against percentage for each constituent. Figure 3 is a copy of such a calibration chart. Care must be taken that samples are run under the same instrumental conditions (temperature, carrier gas flow rate, size of sample, detector voltage) as were used in making the calibration.

In Figure 4 the results of gas analysis for carbon dioxide and the results of volatile acidity determinations for a particular digester are plotted on the same graph. This shows the association between changes in the composition of the gas during changes in the status of the digestion process in the same way as do the determinations of volatile acidity. The carbon dioxide values often indicate a change in the process as much as 24 hours before the volatile acidity values.

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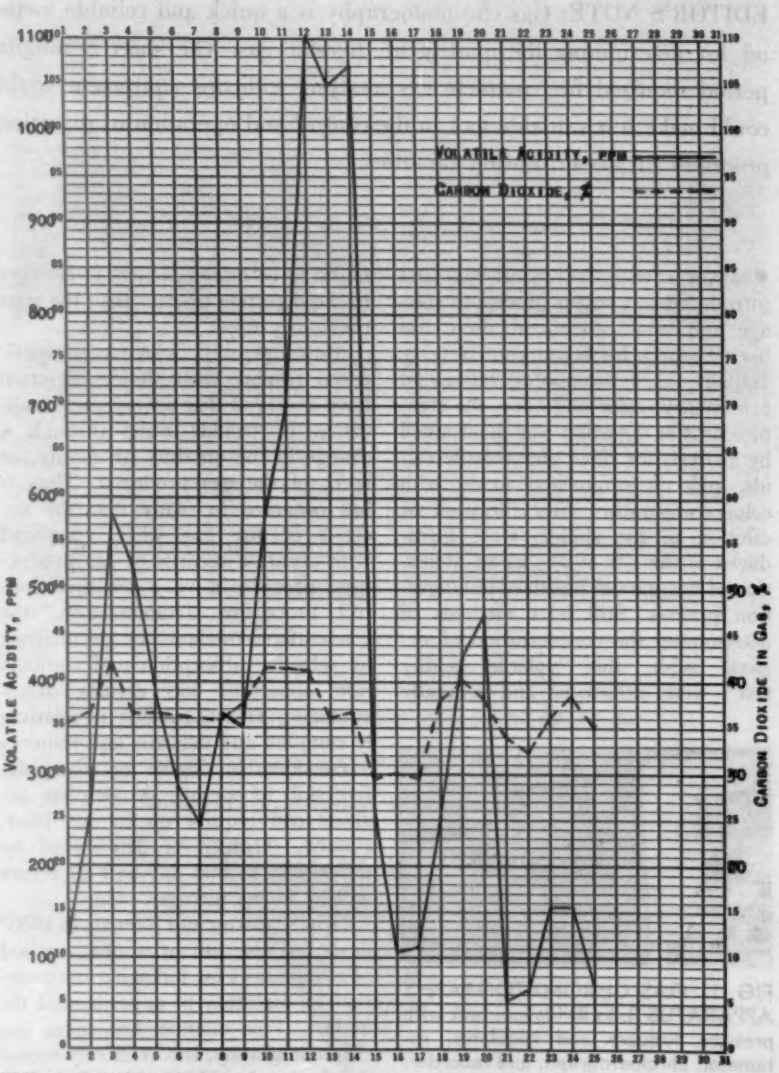

FIG. 4. COMPARISON of carbon dioxide and volatile acids data for functioning digestion process. The increase in carbon dioxide content in the gas often precedes the buildup in volatile acids concentration.

Continuous Gas Analysis may provide better control through . . .

Application of Gas Chromatography to Sludge Digestion Gas Analysis

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RESUME: The search for practical and efficient means to operate digestors continues. This report summarizes eighteen month's devoted to studying partition columns, various partition materials, hydrogen, argon and hydrogen sulfide. Work has been performed under National Institutes of Health Research Grant RG-4945.

The Problem

■ THE CONCENTRATIONS of specific components in sludge digestion gas, such as methane, carbon dioxide, hydrogen sulfide and ammonia, to further basic knowledge of the mechanism of the anaerobic process, have been the subject of many intensive reasearch investigations. The lack of a simple and reliable method for gas analysis has prevented the establishment of precise relationships to support experimental evidence and theory.

Although considerable information has been collected about the composition of gases from digestion, organized research in this area has been difficult and the available data only fragmentary. This research project has been designed to establish the composition of digester gas mixtures from domestic sludges and those containing toxic wastes. It would be useful to follow the course of digestion by complete gas analysis indicating the changes in gas quality with progress of digestion. Such analysis could test several hypotheses, such as the role of hydrogen sulfide during anaerobic digestion, the path of methane fermentation to distinguish between acid cleavage and carbon dioxide reduction to methane by feeding C-14 labelled compounds, and the significance of specific gas components in the mixture.

Purpose of the Study

The purpose of the study is to develop a simple but accurate chromatographic method for the qualitative and quantitative analysis of the gases from decomposition during sludge digestion. The general method of gas chromatography shows real promise as a precise, analytical tool for sanitary scientists. It is expected that with this new technique gas production from anaerobic digestion can be placed on a more rational basis, will improve the fundamental understanding of the mechanism of anaerobiosis and aid in the solution of digester problems.

Another aspect of the study has been to develop a method to accurately determine gas quality and quantity on a continuous basis. With the aid of such a system this method of analysis will also become available to the smaller plants with limited laboratory facilities and trained personnel. Gas chromatography, beyond a gas analyzer, may also provide operational control for the sludge digestion process.

This newly developed technique for sludge gas analysis would: (1) provide treatment plant operators with the information to adjust the daily feed for optimum digestion in accordance with the quality of the gas produced (by means of a simple reading); (2) point the way toward optimum digester operation for maximum methane production (with a minimum of noxious or corrosive gases), and; (3) place into the hands of research workers in the sanitary science and other fields, where fermentation studies are needed, an extremely useful new tool.

Summary of experimental results

Silicone Grease Column for Routine Analysis

A silicone grease partition column, recommended as an optimum column in a previous progress report (1), has replaced the silica gel adsorption column for routine daily analysis. The 71 ft column provides fine separation between air and methane, and complete separation between methane and carbon dioxide, and carbon dioxide and hydrogen sulfide. The column is packed with silicone grease (*) coated firebrick particles of 28 to 48 mesh, with a liquid to solid ratio of 60:100 (by weight) for the first 35 ft, and 35:100 (by weight) for the remaining 30 ft. Compared to the solid adsorption columns previously used, the gas-liquid partition column provides sharper peaks, especially for

carbon dioxide, shorter analysis time, is less affected by water vapor and shows longer service life. The present column has been under continuous service for over one year to analyze at least 20 samples each day and still performs satisfactorily. Excellent reproducibility of better than one per cent has been achieved.

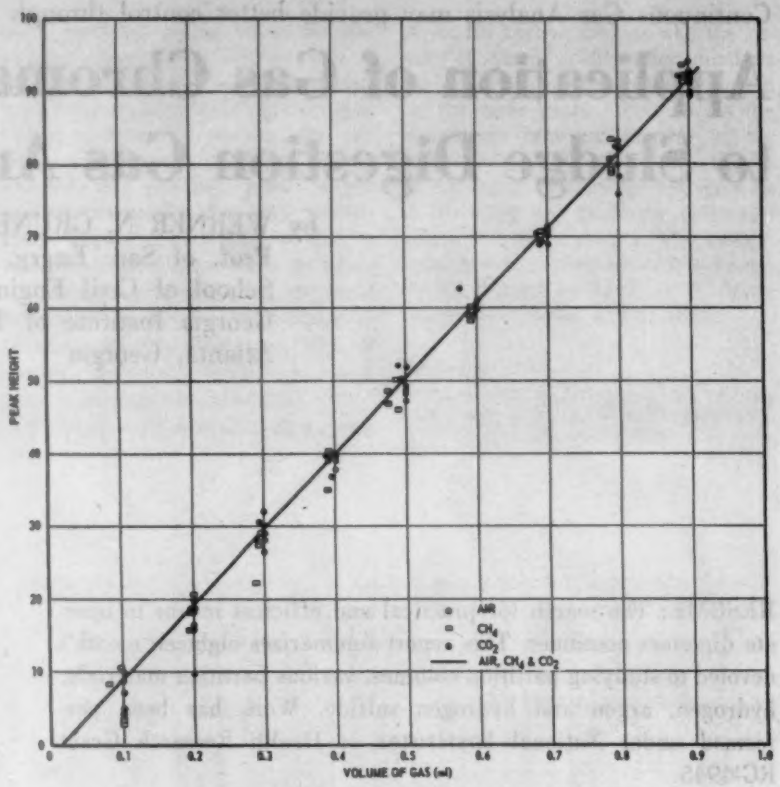
Another special feature of the column is that it produces equal peak heights for the same amount (by volume) of air, CH_4 or CO_2, as shown in Figure 1. This obviates the need for the type of calibration curves which were needed previously, as seen in Figure 2.

Other partition liquids

Organic solvents, other than silicone grease, have been studied for use as coating materials. Their absolute retention volumes, corrected for the pressure drop across the column, expressed as ml per gm of partition liquid, are summarized in Table I below. These retention volumes, which are directly related to the free energy of separation, have been determined experimentally and confirm the theories of Martin and Synge (2) and Martin and James (3), that they are a function of the characteristics of the binary system of gas and fixed liquid phase and the column temperature. Further studies of the limitations of the limitations of these theories and necessary modifications are under way.

It is apparent that silicone grease, silicone oil 550, and tetra-isobutylene have comparable resolving abilities for air, methane, carbon dioxide and hydrogen sulfide, the major components present in sludge gas. Liquid coatings with tetra-isobutylene have been found to produce a slight separation between oxygen and nitrogen.

(*) Dow Corning Stopcock Grease, manufactured by the Dow Corning Corp., Midland, Michigan.



CALIBRATION CURVES FOR AIR, CH_4 AND CO_2

COLUMN: 71 FT. SILICONE GREASE, C-22, 28–48 MESH
FLOW RATE: 102 mls/min.
COLUMN TEMPERATURE: 80°F

FIGURE 1

However, such separation is not sufficient for analytical purposes but introduces the difficulty of interpreting the air peak which varies not only as the quantity but also as the quality of air (N_2 : O_2 ratio) present.

Dimethyl sulfolane possesses a strong resolving ability for carbon dioxide, however it is weak in separating methane from air. Columns coated with tricresyl-phosphate were found to be relatively weak in resolving methane and carbon dioxide. This effect may be due to the polar characteristics of the organic coating liquid which may also be the reason for the column to exhibit a weaker permanent adsorption tendency toward hydrogen sulfide than with other liquid coatings.

Detection of Hydrogen and Argon

Molecular sieve (type 5A) columns combined with a sensitive recorder (0 to 1 mv range) have been used to detect concentrations of hydrogen as low as 16 p.p.m. However, no hydrogen has been found thus far in the sludge gas produced from laboratory digesters. A more systematic and intensified investigation to detect the presence of hydrogen will be initiated shortly. Considerable argon has been found along with nitrogen. These findings tend to confirm the assumption that nitrogen present in sludge gas is introduced from the atmosphere rather than produced during the anaerobic decomposition of sewage sludge.

TABLE I

Experimentally Determined Retention Volumes for Several Organic Partition Liquids

Column Material		Silicone grease	Tri-iso butylene	Tetra-iso butylene	Tri-cresyl-phosphate	Dimethyl sulfolane	Silicone oil 550
Column Temp.		73°F	70°F	75°F	80°F	73°F	77°F
Retention Volume (ml/gm)	CH_4	0.336	0(**)	0.35	0(**)	0.074	0.206
	CO_2	1.13	0.215	1.34	0.484	3.33	1.18
	H_2S	5.00	—	5.10	3.77	—	6.05

(**) No separation between air and methane

Automatic Sampling

After overcoming a number of leakage problems, an automatic sampling valve has been used for routine analysis. Based on ten months of operation, providing satisfactory results, additional refinements of the automatic sampling technique were made. It has been found of paramount importance that the gas sampling line have a minimum distance and bends between the sampling point and the valve in order to inject representative samples.

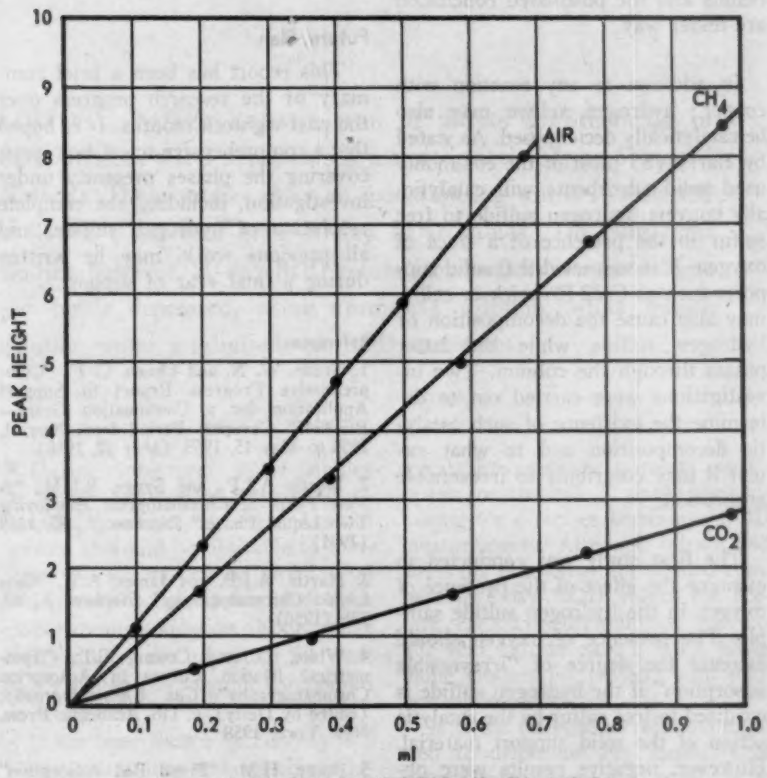
Hydrogen Sulfide

During the last year the work was largely devoted to the analysis of hydrogen sulfide. Solid adsorption columns were found inadequate for the analysis of hydrogen sulfide due to their strong permanent absorption ability. Even gas-liquid partition columns exhibit the same strong tendency of irreversible adsorption. A small hydrogen sulfide sample (less than 0.5 ml) cannot pass through a gas-liquid partition column unless the column has been saturated by a previous hydrogen sulfide sample. By testing various samples with different liquid to solid ratios, it was found that the permanent adsorption ability decreases with an increase of the liquid-solid ratio. Therefore, it appears that the adsorption is caused by the solid support (firebrick, celite, etc.) rather than by the coating liquid.

It has long been recognized that any solid surface with sufficient contact area possesses a certain adsorption power toward gases. The adsorptive power of "inert" solid supports used in a partition column toward hydrogen sulfide was confirmed experimentally by injecting hydrogen sulfide samples into the columns made of firebrick or celite without any liquid coating. From the first few injections no hydrogen sulfide peak or only a small peak appeared and presumably the hydrogen sulfide sample (or the major portion) was "irreversibly adsorbed". After repeated injections the peaks grew larger and then maintained a constant height, indicating that the column had become saturated with hydrogen sulfide. However, the saturated condition was found to be permanent but the column soon became unsaturated again due to the purging action of the carrier gas.

Uncoated firebrick columns also provided good resolution between air and hydrogen sulfide although such resolution must have been caused by the adsorption on the firebrick surface. The adsorption in the latter case may be termed as "reversible adsorption" and should not be confused with the "irreversible adsorption" mentioned previously. The adsorption of carbon dioxide by silica gel at room temperature is reversible because the adsorbed carbon dioxide may be purged back into the gaseous phase by the carrier gas. However, the adsorption of carbon dioxide by molecular sieves is "irreversible" because no carbon dioxide can be recovered by purging the molecular sieve column with helium at room temperature. It is rather difficult to understand that firebrick would possess both adsorption characteristics. This phenomenon may be explained by the presence of sites with varying energies of adsorption on the surface of the firebrick, as has been assumed by White and Cowan (4). Both types of adsorption phenomena of solid supports are undesirable for preparing an efficient partition column, but the "irreversible adsorption" is the main object of attack of the present investigations because it makes the analysis of low concentrations of hydrogen sulfide impossible. Comparing the amount of hydrogen sulfide required to saturate various columns of similar length, it is found that the celite-545 column has a stronger "irreversible adsorption" ability than the C-22 firebrick, although the former does not resolve air and hydrogen sulfide which means that it has a weaker "reversible adsorption" ability than the firebrick.

Various methods of deactivation of firebrick and celite have been investigated. They can be classified as: (a) washing with an alkali solution, such as diluted NaOH; (b) washing with an inorganic acid, such as concentrated or diluted HCl; (c) precoating with an organic compound, such as stearic acid, oleic acid or glycerine;



CALIBRATION CURVES FOR AIR, CH_4 AND CO_2

COLUMN: 12 FT. SILICA GEL, 28 – 48 MESH
FLOW RATE: 80 ml/min.
COLUMN TEMPERATURE: 130°F

FIGURE 2

or (d) mixing the organic compound with the coating liquid such as silicone fluid 550 or triethylene glycol. In some cases a combination of the above methods were employed.

Over 30 columns have been prepared for this particular investigation of the adsorption of hydrogen sulfide. These columns were studied by repeatedly injecting hydrogen sulfide samples of 1,000 p.p.m. in 2 ml of air. Both the amount of sample required to saturate a column before the first hydrogen sulfide peak appears and its height have been used as a basis for the comparison of the irreversible adsorption phenomenon. Two different temperature levels 80° F and 200° F, have been examined along with various flow rates. From the results obtained thus far the following conclusions may be drawn:

(1) Although the "reversible adsorption" of the solid support material is generally weaker (lower resolution power) at high temperatures, the "irreversible adsorption" does not seem to be similarly affected by the temperature. Hydrogen sulfide is adsorbed by firebrick or celite at 200° F as well as at room temperature.

(2) The flow rate exerts no significant effect.

(3) An increase in the pH value of firebrick appears to aid absorption; however, maintaining a pH on the acid side only slightly reduces the normal adsorptivity of the solid support.

(4) The best results have been obtained by the following treatment procedure: To a suspension of 200 gm of the fine meshed C-22 firebrick in 500 ml distilled water add 20 ml of 0.1 N NaOH aq. solution to bring the pH to a value of 10.5. Discard the solution and wash the firebrick with distilled water until its pH reaches a value of 7.3. Dry the firebrick in an oven at 600° F for one hour. Precoat the firebrick with stearic acid (3% by weight of firebrick) before coating with a partition liquid, such as silicone fluid 550.

In an experimental run, 1,000 p.p.m. hydrogen sulfide in a 2 ml air sample appeared after the first injection, although the peak height was low (0.3 unit as compared to 8.0 units peak height obtained after the column was saturated), indicating that a great portion of hydrogen sulfide was irreversibly adsorbed. No significant improvements have thus far been shown by any other method of treatment of solid support materials.

During more recent studies results which may represent a "breakthrough" were obtained when polyethylene instead of copper tubing was used to pack liquid coated particles. The irreversible adsorption of hydrogen sulfide appears to have been eliminated by packing the polyethylene tubing with pretreated firebrick (washed with conc. HCl followed by neutralization with 0.5 N NaOH) and coated with oleic acid (ratio of 2 : 100 of liquid to solid by weight) and silicone fluid 550 (ratio of 50 : 100 of liquid to solid by weight). Therefore, the so called "irreversible adsorption" may be at least in part attributable to the chemical reaction between copper and hydrogen sulfide. Further studies to confirm these results and the postulated conclusion are under way.

In addition to any reaction with copper; hydrogen sulfire may also be catalytically decomposed. As stated by Barry (5) most of the commonly used solid adsorbents will catalytically convert hydrogen sulfide to free sulfur in the presence of a trace of oxygen. It is suspected that solid supports such as C-22 firebrick or celite, may also cause the decomposition of hydrogen sulfide while the latter passes through the column. Two investigations were carried out to determine the existence of such catalytic decomposition and to what extent it may contribute to irreversible adsorption.

The first study was conducted to examine the effect of the presence of oxygen in the hydrogen sulfide sample. The presence of oxygen should increase the degree of "irreversible adsorption" if the hydrogen sulfide is oxidized to free sulfur by the catalytic action of the solid support material. However, negative results were obtained since the presence of oxygen in hydrogen sulfide did not increase the extent of permanent adsorption, but, if anything, reduced it in a few cases.

The second study was made to investigate the effect of low column temperature on hydrogen sulfide adsorption. The favorable temperature for the decomposition reaction of hydrogen sulfide is 200° C, but the decomposition slows down with a decrease in temperature (6). Therefore, if the reaction occurs at all in the gas chromatographic column, it should cease at a low temperature. Experiments were carried out by surrounding the column with dry ice and acetone (−76° C). However, the results obtained were also negative. The irreversible adsorption became stronger at the extremely low temperature and even 2 ml samples of hydrogen sulfide could not pass through a 13 ft long column. Probably the experimental temperature was too low and caused the condensation of hydrogen sulfide gas (b.p. = −61.8° C). Further studies at a temperature of −40° C are scheduled to more fully investigate the effect of low column temperature on the catalytic decomposition of hydrogen sulfide.

Future Plan

This report has been a brief summary of the research progress over the past eighteen months. It is hoped that a comprehensive scientific report, covering the phases presently under investigation, including the complete resolution of hydrogen sulfide, and all previous work, may be written during a final year of support.

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Investigations of long term BOD studies show advantages of . . .

Nitrate as the Nitrogen Source in BOD Dilution Water

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EDITOR'S NOTE: Substitution of nitrate for ammonia in BOD dilution water represents a major deviation from *Standard Methods*. These studies show an oxidation lag which is reflected in lower 5-day and even 10-day BOD values. On long term studies, however, 20-day BOD values increased as sewage volume per bottle decreased, using ammonia dilution, while nitrate dilution water minimized the BOD variations.

■ During long-term BOD studies on newly synthesized organic compounds now present in industrial wastes, it would be desirable to minimize the errors due to nitrification which may occur during and after carbonaceous oxidation. Long range BOD studies are important for such newly synthesized organic compounds as detergents.

It has been shown by Gaffney and Heukelekian[1] that sodium nitrate instead of ammonia in BOD dilution water constitutes a satisfactory nitrogen source for the growth of heterotrophic bacteria fed with sodium acetate, while the substitution of the nitrate for ammonia prevents nitrification for the full 20 days; thus allowing for direct carbonaceous BOD measurements. Although nitrate and ammonia dilution water yielded comparable 5-day BOD values for acetate, carboxymethylcellulose and oxalic acid, nitrate gave a much lower value (longer lag period) with toluene sulfonic acid.

It is the purpose of this investigation to determine the feasibility of substituting nitrate for ammonia in BOD dilution water as the recommendation in *Standard Methods* for long term BOD studies on sewage and and other groups of organic substrates.

Procedure

As nearly as possible, tests were run according to the procedures outlined in the 11th edition of *Standard Methods for the Examination of Water, Sewage, and Industrial Wastes*. Nitrate dilution water was prepared using an equivalent amount of nitrate-nitrogen instead of ammonia in the standard dilution water. In tests using the Warburg respirometer, the nitrogen and phosphorous concentrations were increased in order to maintain a BOD:N:P ratio of 100:5:1. Each BOD value reported represents an average of either three or five replicate tests.

Results

Sewage Analyses

It was the purpose of the initial tests with domestic sewage to illustrate the problem of nitrification in the most common substrate in this field and to show the effect of nitrate substitution and substrate dilution on the BOD values.

Three series of standard dilution bottles were set up with each nitrogen source and with 2, 4 and 6 ml

Table I
Effect of Nitrogen Source and Substrate Concentration on Oxygen Demand of Domestic Sewage
BOD, parts per million

	Days 3		5		10		20	
	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3
2 ml	126	112	196	168	210	210	590	336
4 ml	112	—	154	161	224	224	385	288
6 ml	122	113	150	155	160	165	278	264
Avg.	120	113	170	161	198	200	414	296
Std. dev.±	10	10	22	22	41	34	152	53

of sewage per bottle. BOD values were obtained after 3, 5, 10 and 20 days incubation. The results are shown in Table I and Figure 1.

The data in Table I and Figure 1 show that there was no nitrification in either set of water blanks since there was no seed used in the blanks, but that there is nitrification in the sewage samples. The difference in the 20-day values between the different sewage concentrations with both nitrate and ammonia dilution waters decreases with increasing sample volume per bottle, or with increasing concentration of nitrogenous and organic material. With a given sample volume, the BOD results with either nitrate or ammonia were generally comparable up to and including the 10-day results, but at 20 days the effect of nitrification in the tests with ammonia was significant. With ammonia dilution water the BOD range was 278 to 590 ppm (average = 414 ± 152 ppm), while the range with nitrate was 264 to 336 ppm (average = 296 ± 53 ppm). There was probably some nitrification in the tests using nitrate dilution water because of the ammonia in the sewage. Although the standard deviation was large (18 per cent), the use of nitrate dilution water results in a more realistic 20-day BOD average from all three sewage concentrations.

Other Organic Substrates

The question arose as to what effect nitrate dilution water would have on the BOD of a mixed nitrogenous-carbonaceous substrate. In order to determine this, a test was run using 3.0 and 6.0 ppm glucose-glutamic acid mixtures in standard and nitrate modified dilution water. The results are shown in Table II and Figure 2.

It can be seen from Table II and Figure 2 that comparable BOD values were obtained with either nitrogen source up to a period of 7 days.

Table II
Effect of Nitrogen Source on Oxygen Demand of 3.0 and 6.0 ppm Glucose-Glutamic Acid Mixtures
BOD, parts per million

Days	3.0 PPM mixture NH_3	3.0 PPM mixture NO_3	6.0 PPM mixture NH_3	6.0 PPM mixture NO_3
2	1.1	1.1	2.1	2.3
3	1.2	1.2	2.4	2.5
5	1.0	1.1	2.4	2.6
7	1.2	1.2	2.6	2.8

The next step in the investigation was to determine the availability of nitrate nitrogen in tests with other organic substrates and to determine the feasibility of its use in order to prevent nitrification during long-term BOD measurements. The substrates employed for standard-dilution tests were glutamic acid, starch, sodium formate, glucose and sodium acetate. The results of all these tests are presented in Table III while the BOD curves with only acetate are shown in Figure 3.

It can be seen from these data that in the early oxidation phase (3—5 days) longer lag periods were obtained in the nitrate tests with glucose, acetate, and formate but that the effect of this longer lag was overcome by the 10th day. Conversely, with glutamate and starch, the BOD values with nitrate were slightly higher up to and including the 5th day, although some of this difference may have been caused by the normal variation in experimental technique.

The data in Table III are especially interesting from the standpoint of the decrease in BOD between the 10th and 20th day for all of the strictly carbonaceous substrates that were tested with standard dilution water containing ammonia as the nitrogen source. The values given in the table are corrected BOD's obtained by subtracting the oxygen demand of the sewage seeded blanks from the total oxygen demand in the test bottles. The curves in Figure 3 serve to illustrate the reason for this decrease in BOD. The oxygen demand of the seeded blanks with ammonia dilution water increased from 0.4 to 2.8 ppm between the 10th and 20th day due to nitrification. This means that 2.4 ppm oxygen was used in the oxidation of ammonia. The simultaneous increase in oxygen demand in the sample bottles with acetate was only 1.8 ppm indicating that there was less nitrification in the sample bottles than was observed in the seeded blank. The slopes of the two curves between the 10th and 20th day are different, and it therefore is not a reliable procedure to make BOD corrections on this basis. This error was not obtained where nitrate was substituted in the dilution water since there was no nitrification.

Table III
Effect of Nitrogen Source on Oxygen Demand of Several Pure Organic Compounds
BOD, parts per million

	Days 3		5		10		20	
	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3
Glutamate (5.4 ppm)	2.3	2.5	2.8	3.3	3.3	3.3	3.7	4.0
Starch (5.8 ppm)	2.2	2.4	2.6	2.8	2.9	2.8	1.9	3.2
Glucose (6.0 ppm)	2.8	0	2.9	2.2	3.1	2.6	2.4	3.1
Formate (40 ppm)	0.4	0.3	2.0	0.6	5.4	5.4	4.8	5.4
Acetate (20 ppm)	5.5	0.2	5.8	5.5	6.2	5.4	5.2	5.8
Seed Blanks	0	0	0	0.1	0.4	0.3	2.8	0.3

Nor was the decrease in the calculated BOD between the 10th and 20th days observed with sewage because the blanks, which in this case were not seeded, developed no demand from nitrification. The slopes of the blank and substrate curves with nitrate dilution water were almost the same, so there was no decrease in calculated BOD with sewage seed correction.

Since it had previously been reported[1] that nitrate and ammonia dilution water yielded comparable 5-day BOD's with several compounds, it was pertinent to determine the effect which the contribution of oxygen from nitrate had in lowering 5-day BOD values with glucose. Consequently, another test was run using glucose with five replicates each to compare the 5-day values obtained with nitrate and ammonia dilution water. The results of these tests are presented in Table IV.

Table IV
Effect of Nitrogen Source on 5-Day BOD of Glucose

	5-day BOD, (pts./pt*)	
	NH_3	NO_3
Min.	0.43	0.40
Max.	0.49	0.49
Avg.	0.46	0.45
Std. dev.	±0.04	±0.05

*parts O_2 per part glucose

These data show no difference in the extent of BOD in ammonia or nitrate dilution waters.

Similar tests were run with five different industrial waste samples and the results are presented in Table V.

Table V
Effect of Nitrogen Source on 5-Day BOD of Several Industrial Wastes

		5-day BOD (parts per million)	
Waste	N-Content	NH_3	NO_3
White Water	Deficient	1420	1480
Photographic	Unknown	34	36
Organic dye (1)	NH_3 excess	195	191
Organic dye (2)	NH_3 "	229	199
Organic dye (3)	NH_3 "	205	207

It may be seen from the foregoing results that the 5-day BOD with nitrate was not significantly lower than that obtained using standard dilution water provided that the lag period with nitrate was not excessive.

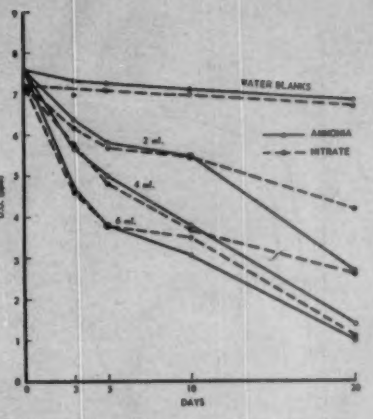

Fig. 1. OXYGEN DEPLETION in bottles using 2, 4, and 6 ml domestic sewage with nitrate and ammonia dilution water.

Discussion

The extent to which nitrification constitutes a problem or interference in BOD tests with various substrates depends on the following factors: nature and concentration of organic substrate (carbonaceous or nitrogenous), duration of test or period of incubation, the use of seeded or unseeded blanks, the number of nitrifiers in the sample and/or seed, the availability of ammonia and carbon dioxide, and the oxygen tension. When pure carbonaceous organic compounds are studied in the BOD test, some nitrogen compound is consumed; therefore, less ammonia will be left for nitrification. This was observed in Table III with acetate. Conversely, nitrogenous organic compounds such as amino-acids will liberate ammonia by deamination and may contribute to a larger oxygen demand from nitrification. The duration of the test and the number of nitrifiers are interrelated: Heukelekian[2] has shown that sufficient seed nitrification may begin immediately, while with a limited seed nitrification may be delayed. Thus, the longer the necessary incubation period for studying a new organic substrate, the more likely the onset of nitrification and the less chance of obtaining a truly carbonaceous oxygen demand. When the dissolved oxygen in a bottle is almost completely consumed by the carbonaceous demand, nitrification may be retarded by the low oxygen tension as shown by Ingols[3]. In order for the oxygen to be used, ammonia and carbon dioxide must be present. Possibly the higher rate of nitrification frequently observed in the later days of long-term BOD studies was a result of the improved carbon dioxide tension after carbonaceous oxidation.

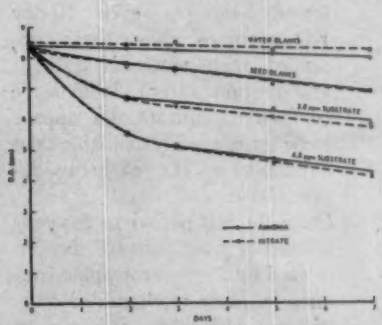

Fig. 2. DEOXYGENATION of glucose-glutamic acid mixtures using nitrate and ammonia dilution water.

In the calculation of BOD values, a special problem arises when seeded blanks are used as controls and the oxygen demand in the blanks is subtracted from the total oxygen demand in the test bottles in order to obtain the differential BOD of the substrate. *Standard Methods* calls attention to this fact and recommends even for standard 5-day tests the use of an actual BOD determination on the sewage seed for calculating the dissolved oxygen in the blank. Thus an amount of BOD proportionate to the volume of seed in the test bottles is subtracted from the total sample BOD. In the very dilute seeded blanks (0.1—0.3 per cent by volume) there is very little heterotrophic bacterial competition for ammonia and/or oxygen; thus, the seeded blank frequently manifests an earlier nitrification than a sewage sample at 2 per cent concentration.

Data obtained in these studies substantiate the favorability of calculated blank procedure even as far as the 5-day BOD is concerned. However, after the 10th day of incubation it is obvious that the calculated blank value to be used in calculating the sample BOD will be affected by the sewage concentration employed in the bottle. Thus, the BOD with the lower sewage concentration (2.0 ml per bottle) is greater than twice that observed with three times that concentration. It has been shown that during the 20-day BOD studies, the wide range in values may be minimized to give a more realistic carbonaceous BOD with smaller average deviation

by substituting nitrate in place of ammonia in the dilution water. In addition to this, the use of nitrate dilution water eliminates the difficulty of interpreting decreasing BOD values between the 10th and the 20th day during oxidation of pure carbonaceous organic compounds where seeded blanks are used with ammonia dilution water. The discrepancy between the extent of nitrification in blanks and sample bottles is eliminated by the presence of nitrates or the absence of nitrification (except for a small amount of nitrification from the ammonia content of the seed).

Although no Warburg analytical data have been presented in this report, it is noteworthy to mention that the authors have never observed anything approaching the theoretical amount of nitrification in Warburg tests using standard dilution water. In the previous article[1] it was concluded that nitrification could be prevented by limiting the amount of ammonia-nitrogen available for carbonaceous oxidation through the use of a BOD:N ratio of 100:5. From more recent analyses and the fact that it appears improbable that the heterotrophic bacteria will consume that much nitrogen, it is considered pertinent to reconsider other possible limiting factors; i.e., the carbon dioxide supply. In order to measure the oxygen uptake directly by the Warburg technique, it is necessary to trap the carbon dioxide produced. It is considered probable that this absence of carbon dioxide from the gaseous phase may be the major limiting factor for nitrification rather than the limited ammonia nitrogen and/or oxygen supply.

The authors also believe that the carbon dioxide requirement for heterotrophic bacteria has not generally been considered as a limiting factor in Warburg BOD determinations or in standard dilution tests. It is probable that the lag periods observed in these tests using high substrate concentrations and very dilute seed may actually be a manifestation of the heterotrophic bacterial requirement for carbon dioxide as a precursor for an important intermediate in the oxidative pathways of the citric acid cycle in the bacteria. Studies that are in progress at the present time dealing with the carbon dioxide requirements for nitrifying bacteria in BOD tests and for eliminating lag periods in both heterotrophic oxidation during BOD tests as well as in waste treatment processes will be the subject of future articles.

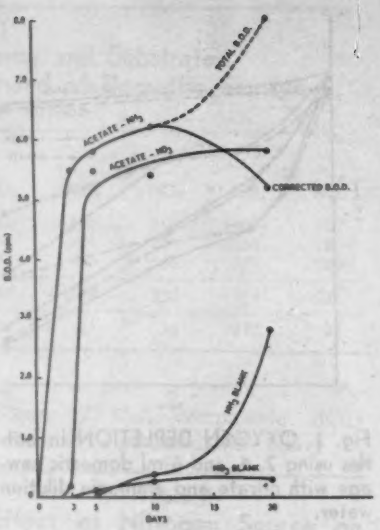

Fig. 3. OXYGEN DEMAND of Sodium Acetate using nitrate and ammonia dilution water.

Conclusions

The investigations were designed to determine the feasibility of substituting nitrate in place of ammonia in the dilution water used for BOD studies on sewage, industrial wastes, and single organic substrates. On the basis of the data obtained it may be concluded that:

1. Nitrate constitutes a satisfactory nitrogen source for the bacterial oxidation of all the substrates studied although it may not, in certain cases, be as readily available as ammonia in the early oxidation phase. The resultant lag in oxidation with nitrate dilution water may yield lower 5-day or even 10-day BOD values than those observed with ammonia (standard dilution water). With some compounds, nitrate did appear to be more readily available than ammonia in the early oxidation phase.
2. Once the lag period in oxygen-uptake is over, nitrate oxygen is used by the heterotrophic bacteria in place of dissolved oxygen gas when there is a nitrate nitrogen demand, and thus the observed BOD tends to be lowered. However, the data indicate that this decrease in observed BOD is too slight to warrant any considerable attention since the advantages far outweigh these disadvantages in certain cases.
3. The advantages of using nitrate in BOD dilution water are threefold with respect to long-term BOD studies.
   (a) In BOD tests on sewage using ammonia the 20-day BOD values increased from 278 to 590 ppm as the sewage volume per bottle decreased from 6.0 to 2.0 ml. Substitution of nitrate dilution water minimized these BOD variations and yielded an overall average in substantial agreement with the highest sewage concentration in ammonia dilution water (where oxygen tension was lacking for extensive nitrification and where the nitrification of any ammonia in the dilution water was multiplied by a smaller dilution factor).
   (b) Tests on pure organic substrates require artificial seeding and it is necessary to include seeded blanks. When the amount of nitrification in these blanks exceeds that observed in the sample bottles where the heterotrophs have used some ammonia between 10 and 20 days, the correction for the seed results in observed decreasing BOD values. Since there is only slight nitrification in the seeded nitrate dilution water (due to the ammonia in the sewage seed), this oxygen demand of nitrification is eliminated by nitrate substitution and the BOD does not decrease.
   (c) In tests using nitrate dilution water, once carbonaceous oxidation is complete, oxygen-uptake ceases and the long term (20 day) BOD value better represents the ultimate carbonaceous BOD of any particular carbonaceous substrate.

In addition, corollary information derived from these studies has led

to the following conclusions:

4. The recommendations presented in *Standard Methods* concerning the handling of seed blanks where artificial seeding with sewage is required should be followed to minimize BOD errors. However, the procedure of running a complete BOD on the sewage seed and subtracting a proportionate amount based on seed concentration in the test bottles does not eliminate the error in 20-day values unless nitrate is used in the dilution water.
5. Further studies should be made concerning the carbon dioxide requirements for the nitrifying organisms and the heterotrophic bacteria involved in Warburg and Standard Dilution BOD tests.

Acknowledgement

This study was supported by a grant from the Division of Research Grants, National Institute of Health. U. S. Public Health Service.

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Both as an introduction for some and as a review for others, presented here are . . .

Some Applications of Elementary Solution Equilibrium Chemistry

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EDITOR'S NOTE: Some comprehension of the principles underlying the subject of equilibrium chemistry as applied to water is necessary for a more complete understanding of new developments in corrosion prevention, controlled scale formation, water softening, and waste treatment. This paper presents these principles in a concise and readily understandable manner for those interested in the production of *Quality Water*.

■ AN INSPECTION of a number of short course proceedings and undergraduate texts in the water and waste field reveals that equilibrium chemistry is usually not offered with the instructional material.* While the subject us usually introduced in the first chemistry courses, the student comes to realize the full value of the material only in later courses. Since the more advanced of the elementary chemistry courses are not included in a typical civil engineering curriculum, this appreciation might not be reached by many workers in the field. This is perhaps unfortunate, since equilibrium chemistry can bring added depth of understanding to many of the phenomena in water and waste treatment. The intention of this paper is to substantiate this statement by demonstrating some applications of elementary equilibrium chemistry.

Mass Law

The case for equilibrium chemistry is revealed almost at once in its origin. C. L. Berthollet, while serving as scientific adviser to Napoleon, noticed that certain salt lakes in Egypt had significant deposits of sodium carbonate. Apparently a reaction was taking place which was in the opposite direction to the laboratory experiment in which sodium carbonate reacts with calcium chloride to precipitate calcuim carbonate. Berthollet's conclusion was that the high concentration of sodium chloride and dissolved calcium carbonate was responsible for the reversal of the laboratory reaction. Thus in 1799 there was a clear understanding (by at least Berthollet) that the concentration of reactants can influence the extent of the reaction and composition of the products.

Despite some opposition, Berthollet's work was slowly amplified into a foundation which reached its culmination in the law of mass action as presented by Guldberg and Waage about 1867. According to this law, the rate of a chemical reaction is proportioned to the active masses of the reacting substances. The active mass was initially interpreted as the molecular concentration of the substance.

Equilibrium Constant

The mass action law was recognized by Guldberg and Waage as a convenient means to establish quantitative relationships in chemical equilibria. Today we express this in terms of an equilibrium constant, K, which is readily derivable from the mass action law.

As an example, we might take the reaction of A and B to form products C and D. Expressed as a reversible chemical reaction, this may be written

$$A + B \rightleftarrows C + D \qquad (1)$$

According to the mass action law, the rate at which A and B react is proportional to the concentration of each. Expressing the molecular concentrations of A and B by adding parentheses, the mass action law states that the reaction rate to the right is proportional to (A)(B). For ease in mathematical formulation, a constant of proportionality, k_r, is introduced as follows:

$$\text{Rate (to right)} = k_r(A)(B)$$

The rate of the reverse reaction of C and D to form A and B may be similarly expressed:

$$\text{Rate (to left)} = k_l(A)(B)$$

When equilibrium exists, the reactions to the right and left are equal. Under these conditions:

$$k_r(A)(B) = k_l\,(C)(D)$$

or

$$k = \frac{k_r}{k_l} = \frac{(C)(D)}{(A)(B)} \qquad (2)$$

The equilibrium constant, K which is substituted for k_r/k_l is thus ex-

*A text which is an exception has become available since this paper was prepared. See *Chemistry for Sanitary Engineers* by C. N. Sawyer, McGraw-Hill, 1960

pressed in terms of concentrations, usually molar.

A more general form of equilibrium constant may be deduced if a slightly more complex reaction is considered. Suppose, for example, a reaction similar to (1) except that two moles of B are involved. This reaction is:

$$A + 2B \rightleftarrows C + D$$

This may also be written:

$$A + B + B \rightleftarrows C + D$$

The reaction rate to the right now becomes:

Rate (to right) $= k_r(A)(B)^2$

and it follows that the equilibrium constant is defined by:

$$K = \frac{(C)(D)}{(A)(B)^2} \qquad (3)$$

Equation (3) suggests that for the general reaction of the type:

$$mA + nB \rightleftarrows pC + qD$$

The appropriate equilibrium constant is:

$$K = \frac{(C)^p(D)q}{(A)^m(B)^n} \qquad (4)$$

Equation (4) is the basis for the examples cited in this paper. The interested reader with the necessary background will find that it is possible to derive (4) from thermodynamic principles, and that in fact K has a derivable relationship with energy changes involved in the reactions.[1] Fortunately, these more sophisticated aspects of the equilibrium constant need not be measured to utilize the constant. However, there are certain factors which must be kept in mind. First, the constant changes with temperature, and secondly, strict adherence to equation (4) is followed only in very dilute solutions. This latter problem was overcome by the introduction of the concept of activity.

Activity

When it was observed that equation (4) was not adequate except in very dilute solutions, Lewis introduced the activity coefficient, which is commonly denoted by the letter f (or the Greek letter gamma). The product of f and the concentration is termed the activity. Since f is a dimensionless factor having a value from zero to unity, activity has the same units as concentration.

The activity coefficient was originally thought of as an empirical modifying factor. The need for such a factor was based upon observation that the effective concentration of a material in solution decreased as the concentration of electrolytes increased. This behavior was ascribed to interionic attraction. (A very crude analogy would be to compare the progress of an individual attempting to walk rapidly along a busy street with his progress along a country lane.) Subsequently the whole concept of activity was put on a strong theoretical basis by the work of Debye and Hückel, and it is now possible to compute activities from theoretical considerations.[2, 3]

The substitution of activity for molar concentration, therefore, requires the ability to calculate the activity coefficient. Fortunately, many water and waste solutions are quite dilute so that it is permissible to apply a coefficient of unity for purpose of calculation. Also, since equilibria concepts are valuable for qualitative as well as quantitative reasoning, much can be learned about various phenomena without resorting to calculation of activity coefficients. However, some phenomena, such as the increased solubility of $CaCO_3$ in salt over that in pure water, can only be explained on the basis of activities.

With this qualification in mind we may now proceed to the various specialized types of equilibrium constants of interest in water and waste engineering.

Specialized Equilibrium Constants

The most useful type of specialized equilibrium constant in water work is the dissociation constant for weak acids. If one takes an acid such as hypochlorous acid in contact with water the reaction is:

$$HOCl + H_2O \rightleftarrows H_3O^+ + OCl^- \qquad (5)$$

The equilibrium constant is then:

$$K' = \frac{(H_3O^+)\quad(OCl^-)}{(HOCl)\quad(H_2O)}$$

Now the undissociated water concentration, (H_2O), is considered as a constant quantity and may be multiplied by K′ to give the dissociation constant K:

$$K = K'(H_2O) = \frac{H_3O+)\quad(OCl-)}{(HOCl)} \qquad (6)$$

The use of the hydronium ion, (H_3O^+), is adhered to by many writers since the hydrogen ion is apparently hydrated, but the simpler form, utilizing the more familiar hydrogen ion concentration, (H^+), is numerically equivalent and will be used in this paper. Thus (6) becomes:

$$K = \frac{(H^+)\quad(OCl^-)}{(HOCl)} \qquad (7)$$

This form suggests that the original reaction (5) could have been written:

$$HOCl \rightleftarrows H^+ + OCl^- \qquad (8)$$

When more than one hydrogen exists in the acid the convention is to show the dissociation in step-wise form, giving the ionization constant a subscript of 1, 2, 3, etc.

For a dibasic acid such as carbonic acid the dissociation steps are:

$$H_2CO_3 \rightleftarrows H^+ + HCO_3^-$$

and $$HCO_3^- \rightleftarrows H^+ + CO_3^-$$

The dissociation constants are, therefore:

$$K_1 = \frac{(H^+)\quad(HCO_3^-)}{(H_2CO_3)} \qquad (9)$$

$$K_2 = \frac{(H^+)\quad(CO_3^-)}{(HCO_3^-)} \qquad (10)$$

Other useful forms of the equilibrium constant are the various solubility products and the ionization constant for water. The solubility product is formed by considering the concentration of the solid material as a constant. For example, consider the reaction by which solid magnesium hydroxide dissolves to form magnesium and hydroxyl ions:

$$Mg(OH)_2 \rightleftarrows Mg^{++} + 2OH^- \qquad (11)$$
(solid)

The equilibrium constant is:

$$K' = \frac{(Mg^{++})\quad(OH^-)^2}{(Mg(OH)_2)}$$

The concentration of solid $Mg(OH)_2$ is multiplied by K′ to yield K_s, the solubility product:

$$K_s = K'(Mg(OH)_2) = (Mg^{++})(OH^-)^2 \qquad (12)$$

Equation (12) demonstrates the reason why the addition of lime decreases the solubility of magnesium hydroxide in water softening. The hydroxide ions from the dissolved lime add to the OH^- concentration in parentheses in (12). Since the product, K_s, is a constant, the value of (Mg^{++}) must decrease. Since (Mg^{++}) represents the dissolved magnesium hydroxide from (11), it is obvious that the concentration of magnesium hydroxide must decrease and it therefore precipitates.

In the case of the ionization constant for water, the dissociation is: $H_2O \rightleftarrows H^+ + OH^-$ and the equation for the equilibrium constant is:

$$K' = \frac{(H^+)\ (OH^-)}{(H_2O)}$$

As before, the concentration of undissociated H_2O is considered as a constant and is multiplied by K' to give the ionization constant, K_w, which is unique for water:

$$K_w = K'(H_2O) = (H^+)\ (OH) \qquad (13)$$

On inspecting this equation, it can be seen that, no matter how high the concentration of hydroxyl ions may be, there must remain sufficient hydrogen ions to satisfy the equation. Therefore, in expressing either the active acidity or alkalinity of a water solution, it is sufficient to give only the hydrogen ion concentration. From this, the hydroxyl ion concentration may easily be calculated.

In arriving at these various specialized constants, it was observed that not only could the values be manipulated algebracially, but that if logarithms were taken, useful expressions could be derived for special situations. For example, early investigators found that expressing the hydrogen ion concentration as gram ions per liter gave a value that was awkward to use. In much of their work the term, $\log \frac{1}{(H^+)}$, occured, and it was seen that this term defined the hydrogen ion concentration as accurately as the term, (H^+). For simplicity the value for the term, $\log \frac{1}{(H^+)}$, was given the symbol, pH.

This same convention can also be applied to any of the concentrations in these equations for dissociation constants and also to the constants themselves. Equation (13) may therefore be rewritten as: $pK_w = pH + pOH \qquad (14)$

At 25°C. the value for K_w is almost exactly 1.0×10^{-14} and pK_w is then, 14. At this temperature, therefore, pOH can always be found as the difference between 14 and the pH value. For example, after softening, a water might have, at 25°C., a pH of 9.85. The pOH would be 4.15. Since these are negative logarithms they must be converted to the usual form. 9.85 becomes 10.15, for which the antilog is 1.41×10^{-10}, the actual hydrogen ion concentration as gram ions per liter. The pOH value of 4.15 becomes 5.85, for which the antilog is 7.08×10^{-6}, the hydroxyl ion concentration as gram ions per liter. This may be expressed as mg. $CACO_3$ per liter by multiplying by 50,000. Thus, at 25°C., in a water having a pH value of 9.85, the hydroxyl ion concentration, as mg. $CaCO_3$ per liter is $50{,}000 \times 7.08 \times 10^{-10}$ or 3.54. Either the pOH value or the hydrogen ion concentration found above could then be used in equation (12) or its equivalent: $pK_s = 2pOH - \log(Mg^{--})$ to predict the minimum concentration of magnesium that could be expected in a water with a pH of 9.85.

Buffering and pH Indicators

A buffered solution is one which has capacity for receiving an acid or base without alteration in pH. This becomes possible when the strongly dissociating salt of a weakly dissociating acid is combined with the acid. This may be demonstrated for acetic acid. The reaction is:

$$HC_2H_3O_2 \rightleftarrows H^+ + C_2H_3O_2^-$$

The dissociation constant is given by:

$$K = \frac{(H^+)\ (C_2H_3O_2^-)}{(HC_2H_3O_2)} \qquad (14)$$

Taking logarithms of both sides and rearranging:

$$-\log (H^+) = -\log K + \log \frac{(C_2H_3O_2^-)}{(HC_2H_3O_2)}$$

Utilizing the convention that the negative logarithm of a quantity can be expressed by inserting a p before the quantity, there results:

$$pH = pK + \log \frac{(C_2H_3O_2^-)}{(HC_2H_3O_2)} \qquad (15)$$

In a buffered solution the salt supplies the acetate ion and the acid provides the undissociated acid. When a given quantity of hydrogen ions are added from an external source the $(HC_2H_3O_2)$ will increase and the $(C_2H_3O_2^-)$ will decrease by the given amount. If this change is small compared with the original concentrations, the ratio will be little affected and the pH will therefore remain approximately constant (since pK is constant). An analagous situation will occur if hydroxyl ions are added from an external source.

A similar approach is used to understand pH indicator solutions, which are weak acids. Designating an indicator solution by the shorthand form HIn, the reaction is:

$$HIn \rightleftarrows H^+ + In^-$$

Taking logs and rearranging:

$$pH = pK + \log \frac{(In^-)}{(HIn)} \qquad (16)$$

Since the color of pH indicators depends upon whether it is in the form of the ion, In^-, or the undissociated molecule, HIn, it is apparent from (16) that the color will change with pH of the solution.

Other useful information can also be obtained from manipulation of the equilibrium constant. Two excellent examples of this would include the ability to predict the form which a compound might take at varying pH, and the well known Langelier saturation index.

Form of Compound Versus pH

One of the most useful applications involving manipulation of equilibrium constants involves the form which CO_2 will take in water. Let us take, for example, a water containing CO_2 at a relatively low pH. The CO_2 will be loosely bound to form H_2CO_3. If the pH is artificially increased by the addition of, say, sodium hydroxide, the solution will gradually take on in turn the characteristic of sodium bicarbonate, $NaHCO_3$, and sodium carbonate, NA_2CO_3. The technique described below permits the determination of the fractions of CO_2 which will appear as carbonic acid, bicarbonate, or carbonate at various levels of pH. If these are designated as x, y, and z respectively the following relationships are written down immediately.

$$x = \frac{(H_2CO_3)}{(H_2CO_3) + (HCO_3^-) + (CO_3^-)}$$

$$y = \frac{(HCO_3^-)}{(H_2CO_3) + (HCO_3^-) + (CO_3^-)}$$

$$z = \frac{(CO_3^-)}{(H_2CO_3) + (HCO_3^-) + (CO_3^-)}$$

An expression for x is now obtained by dividing through by (H_2CO_3):

$$x = \frac{1}{1 + \frac{(HCO_3^-)}{(H_2CO_3)} + \frac{(CO_3^=)}{(H_2CO_3)}}$$

This expression for x is put in terms of K_1, K_2 and (H^+) by using expressions (9) and (10).

$$x = \frac{1}{1 + \frac{K_1}{(H^+)} + \frac{K_1K_2}{(H^+)^2}} \quad (17)$$

Similarly it can be shown that

$$y = \frac{1}{1 + \frac{(H^+)}{K_1} + \frac{K_2}{(H^+)}} \quad (18)$$

$$z = \frac{1}{1 + \frac{(H^+)}{K_2} + \frac{(H^+)^2}{K_1K_2}} \quad (19)$$

It is now obvious that for values of K_1 and K_2 taken from handbooks or the literature[3], x, y, and z may be computed for any value of pH. In fact, the simplest procedure for use of this technique is to prepare graphs showing the fractions versus pH. In the use of these equations it may be observed that, when one measures a pH by potentiometric technique, the activity and not the concentration is obtained. From this standpoint the equations (17), (18) and (19) should hold well quantitatively.

These equations, like that of the Langelier index which follows, are useful examples of the value of the equilibrium constant.

Langelier Index

The Langelier saturation index was introduced in order to give a quantitative idea of the tendency of a given water to precipitate or dissolve $CaCO_3$. The index I is denoted as follows:

$$I = pH - pH_s \quad \ldots(20)$$

In (20), pH is the observed pH of the water and pH_s is the calculated pH at saturation with $CaCO_3$. If I=O, the water is stable. If I is positive, the water is oversaturated with calcium carbonate and tends to be deposit forming. When I is negative, the water is undersaturated with $CaCO_3$ and could tend to be aggressive.

The basic reaction is then one in which solid $CaCO_3$ film in a pipe would be subject to destruction:

$CaCO_3 + H^+ \rightleftarrows Ca^{++} + HCO_3^-$ (film)

The equilibrium constant, as in equation (13) incorporates the solid material:

$$K = \frac{(Ca^{++})\ (HCO_3^-)}{(H^+)} \quad (21)$$

At saturation (21) becomes:

$$K = \frac{(Ca^{++})\ (HCO_3^-)}{(H_s^+)}$$

Rearranging and taking logarithms:

$$pH_s = p(Ca^{++}) + p(HCO_3^-) - pK \quad (22)$$

Introducing the solubility product for $CaCO_3$ and the second ionization constant for carbonic acid,

$$K_s = (Ca^{++})\ (CO_3^=) \qquad K_2 = \frac{(H^+)\ (CO_3^=)}{(HCO_3^-)}$$

Substituting these expressions in equation (21),

$$K = \frac{K_s(CO_3^=)\ (H^+)}{K_2(CO_3^=)\ (H^+)} = \frac{K_s}{K_2} \quad (23)$$

Taking logarithm of (23) after simplifying,

$$-pK = pK_2 - pK_s \quad (24)$$

Substituting (24) into (22),

$$pH_s = p\ (Ca^{++}) + p\ (HCO_3^-) + (PK_2 - pK_s) \quad (25)$$

Equation (25) permits calculation of pH_s and, therefore, I if the calcuim and alkalinity and pH are known. The appropriate additional equations are (13) and (18). However, it is probably more customary to calculate the saturation index from prepared nomographs.[4] Like many other situations in engineering, prepared equations and nomographs may be more intelligently used and interpreted if their origin is understood.

Summary:

A number of examples of the important uses of elementary solution equilibrium chemistry have been cited in order to provide support for the conclusion that these concepts are deserving of greater emphasis in undergraduate and short course work in water and waste treatment.

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An improved method is proposed for the . . .

Colorimetric Determination *of* Chlorine Dioxide in Water

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EDITOR'S NOTE: The presently accepted methods for determination of chlorine dioxide are mostly applications of methods for the determination of chlorine. As a result, they do not differentiate between chlorine dioxide and other sources of chlorine in solutions which contain mixtures of materials used for chlorination. In this paper, the author describes a method he has developed that can be used to determine the relative quantities of chlorine dioxide, chlorine, and chloramines in a mixture of these materials. The basis for this determination is the Palin Method for Differential Titration for Free Chlorine, Monochloramine and Dichloramine which is given in the current edition of Standard Methods as a tentative method.

■ THE DPD METHOD for determining chlorine and chloramines in water may also be used to determine chlorine dioxide. In colorimetric methods so far suggested for this determination, for example that using ortho-tolidine, only about one-fifth of the total available chlorine appears to respond so that the methods are consequently lacking in sensitivity.

The fraction that appears in this way actually corresponds to the change from chlorine dioxide to the chlorite ion. Ingols[1] has already drawn attention to the fact that in the author's first differential titration procedure for chlorine and chloramines, which uses neutral ortho-tolidine as indicator, this change is included in the first step of the technique; that is in the fraction normally corresponding to free chlorine. The same effect is observed in the more recent DPD procedure which uses diethyl-p-phenylene diamine as indicator instead of ortho-tolidine and which, incidentally, has the advantages of more stable colors, fewer reagents and full response from dichloramine in neutral solution. This new procedure gives chlorine, monochloramine, dichloramine and, where necessary, nitrogen trichloride, (Palin[2]).

Method

Using the DPD indicator, a full response may be obtained from chlorine dioxide if the sample is first acidified in the presence of potassium iodide and subsequently brought to an approximately neutral pH by adding sodium bicarbonate. The color so obtained corresponds to the total available chlorine content of this compound. It is, therefore, a simple matter to devise a procedure for its determination using the DPD test solutions, the preparation of which is shown in Table 1.

Five ml. of each solution are used per 100 ml of sample. As these reagents are now available combined together in the form of a stable powder this, because of its greater convenience, is used in the procedure outlined below.

Determination of Chlorine Dioxide

To 100 ml of sample add a few crystals of KI and 1 ml of 5 percent v/v H_2SO_4. After mixing and standing 1 min. to ensure complete reaction add about 0.5 g DPD powder and 4 ml of 5 per cent $NaHCO_3$ solution and again mix. Titrate any red color with stand-

Table I
Preparation of Solutions

1. Dissolve 0.1 g DPD oxalate or 0.15 g DPD sulfate ($NH_2\ C_6H_4\ N(C_2H_5)_2\ H_2SO_4\ 5H_2O$) in chlorine-free distilled water to which 2 ml of 10 per cent (by volume) sulfuric acid and 2.5 ml. of 0.8 per cent disodium ethylenediamine tetraacetate dihydrate (EDTA) have been added. Make up to 100 ml, store in an amber bottle, and discard when discolored.
2. Dissolve 2.4 anhydrous disodium hydrogen phosphate and 4.6 g potassium dihydrogen phosphate in distilled water. Add 10 ml. 0.8 per cent EDTA solution and make up to 100 ml. Add 20 ppm mercuric chloride if necessary, for prevention of mold growth.

Table 2

Amount of Sodium Chlorite Interference

Total Sodium Chlorite ppm available chlorine	Amounts appearing in DPD Procedure Step 1	Step 2	Step 3
1.10	0.00	0.00	0.03
2.20	0.00	0.01	0.05
3.53	0.00	0.02	0.19
4.51	0.00	0.03	0.27

ard FAS solution to a colorless end point. Alternatively match the colors against the permanent standard color glasses.*

Determination of Chloride Dioxide, Free Chlorine and Chloramines

As already noted chlorine dioxide appears with free chlorine in the first fraction of the normal DPD procedure but only to the extent of one-fifth of its available chlorine content. Since this corresponds to the change from chlorine dioxide to chlorite, it was necessary to determine the extent of any interference in the second and third fractions of the procedure; that is, monochloramine and dichloramine respectively, due to the presence of chlorite in the system at this stage. To investigate this the behaviour of solutions of sodium chlorite in the normal chlorine-chloramines procedure was studied with the following results. The figures given for total sodium chlorite are those obtained by applying the above acid-KI technique.

*Available from Tintometer Ltd., Salisbury, England.

It seems evident that following the first stage reaction in the DPD procedure the sodium chlorite derived from the amounts of chlorine dioxide likely to be encountered in practice is without significant effect upon the subsequent determination of monochloramine and dichoramine. Accordingly it is possible to set down a simple procedure for the determination of a mixture of chlorine dioxide, free chlorine, monochloramine and dichloramine upon the following basis.

Normal DPD method gives
(1) $Cl_2 + \frac{1}{5} ClO_2$ (2) NH_2Cl (3) $NHCl_2$

Acid modification gives
$Cl_2 + ClO_2 + NH_2Cl + NHCl_2$

The difference in the respective totals gives four-fifths of the ClO_2 content from which a correction may be applied to the normal step (1) result to get free chlorine.

The first procedure, therefore, would be the same as that given above for ClO_2 except that in the presence of chlorine and chloramines the figure now obtained corresponds to the total available chlorine content. To a second 100 ml of sample add approximately 0.5 g DPD powder, mix and titrate any red color with FAS solution to get Cl_2 plus one-fifth of the ClO_2 present. Add a small crystal of KI and titrate any further color to get $NHCl_2$. Then add 0.5 to 1 g of KI and stand 2 min. to get $NHCl_2$. Deducting the sum of these fractions from the figure obtained for total available chlorine using the acid modification gives four-fifths ClO_2.

The calculations required to obtain the separate amounts of Cl_2, ClO_2, NH_2Cl and $NHCl_2$ are quite simple. In systems where only Cl_2 and ClO_2 are likely to be present, the second and third fractions of the normal DPD method may be omitted when the proposed procedure and the necessary calculations become even simpler.

When using commercial colorimeters and comparators it has been found convenient, especially in the field, to use reagents in the form of standardized tablets*.

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*Available from Messrs. Houseman & Thompson Ltd., Burnham, England or from The Thermidaire Corporation Ltd., Toronto, 5.

Water mains can be put into operation more quickly by using the . . .

Membrane Filter Technique

By I. J. BENEDICT
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EDITOR'S NOTE: The Membrane Filter technique can speed up considerably the bacteriology involved in water works operation. Advantages of the technique given here far outweigh the disadvantage given of cost per sample. Used primarily as a "go, no-go" gauge, this discussion includes comparisons between MF and Standard Methods procedures. Samples from all kinds of distribution system piping are included in the study.

■ SAN ANTONIO derives its water supply from wells which produce very high quality water, with virtually no coliform contamination. Positive samples for this group of organisms have been rare over the years. Considerable attention is therefore paid to distribution system work which could introduce incidental contamination. Such work includes laying of new mains, repairing breaks and miscellaneous activities. All newly constructed mains are withheld from service until they have been demonstrated to be free from contamination. Because of the time saved, the Membrane Filter technique has been used on main disinfection samples. The method is not used on samples reported to health authorities, although good correlation has been obtained between the Membrane Filter and Fermentation Tube methods. This paper will summarize work which illustrates this correlation.

Comparative Sampling

The Membrane Filter was first used in our laboratory during February, 1957. As of December, 1958, a total of 2451 samples was analyzed during the 22 month period. This total includes samples from 312 water main construction projects involving cast iron, steel, cement-asbestos and reinforced concrete steel cylinder pipe.

Dual analyses were performed on main disinfection samples to check the two bacteriological methods against each other. Typical results are listed in Table 1. Following release of the mains, census tract samples were taken from the existing system to check further on reliability of the disinfection procedures. Results shown in Table 2 are typical of those obtained. Supply

Table 1
Comparative Results: Membrane Filter vs Standard Methods Main Construction Projects

Date	Project	Chlorine Residual	M. F.	S. P. C.	Standard Method Presumptive 24	Standard Method Presumptive 48	Confirmatory 24	Confirmatory 48	E. M. B.
2-20-58	1	0.1	-	0	-	5	-	-	-
	2	0.1	-	0	-	5	-	-	-
	3	0.0	Conf +	400	5	5	5	5	A/A, E.
2-23-58	4	0.0	TNC	150	5	5	5	5	A/A, E.
	5	0.0	TNC	180	5	5	5	5	A/A, E.
2-25-58	6	0.5	-	45	-	5	-	-	-
	7	0.5	-	30	-	5	-	-	-
	8	0.2	-	0	-	-	-	-	-
2-26-58	9	0.2	-	1	-	-	-	-	-
	10	0.2	-	1	-	-	-	-	-

M. F. Molecular membrane
S. P. C. Standard Plate Count
E. M. B. Eosin methylene blue
Conf Confluent
TNC Too Numerous to Count
A/A Aerobacter aerogenes
E Eschericia coli

Table 2
Comparative Results: Membrane Filter vs Standard Methods Census Tract— Distribution System Samples December, 1958

Census Tract	Standard Method Prior to Molecular Filter Date	Result	Molecular Filter Date	Result	Standard Method Subsequent to Molecular Filter Date	Result	Census Tract
47	12-8	-	12-15	-	12-23	-	47
48	12-8	-	12-15	-	12-23	-	48
49	12-8	-	12-15	-	12-23	-	49
50	12-8	-	12-15	-	12-23	-	50
51	12-8	-	12-15	-	12-23	-	51
52	12-8	-	12-15	-	12-23	-	52
53	12-8	-	12-15	-	12-23	-	53
54	12-8	-	12-15	-	12-23	-	54
55	12-8	-	12-15	-	12-23	-	55
56	12-8	-	12-15	-	12-23	-	56

Table 3
Comparative Results: Membrane Filter vs Standard Methods Main Stations & Tank Samples December, 1958

Designation	Standard Method Prior to Molecular Filter		Molecular Filter		Standard Method Subsequent to Molecular Filter		Designation
	Date	Result	Date	Result	Date	Result	
Station	12-12	-	12-15	-	12-16	-	Station
Station	12-12	-	12-15	-	12-16	-	Station
Station	12-12	-	12-15	-	12-16	-	Station
Station	12-12	-	12-15	-	12-16	-	Station
Tank	12-12	-	12-15	-	12-16	-	Tank
Tank	12-12	-	12-15	-	12-16	Not-Sampled	Tank
Tank	12-12	-	12-15	-	12-16	-	Tank
Tank	12-12	-	12-15	-	12-16	-	Tank
Tank	12-12	-	12-15	-	12-16	-	Tank
Tank	12-12	*	12-15	-	12-16	-	Tank

*Determined to be a result of sampling technique. Subsequent samples negative.

mains to new construction sections were sampled for control purposes. Table 3 illustrates comparative results of main station and tank samples taken as controls. In the entire program only three cases of non-conformity between Membrane Filter and Standard Methods have been encountered, and these were isolated single samples. Table 4 includes these samples and further demonstrates the extent of agreement between the two procedures. Table 4 also represents results of sampling prior to release of new mains as well as sampling following release to service. Any difference in quality is immediately detected and data may also be used for correlating techniques as noted above.

Membrane Filter Advantages

Among the advantages of the Membrane Filter procedure over Standard Methods is the speed with which results are available. Completion according to Standard Methods requires 5 days, while results with the filter are available in 18 hours. This means a main disinfection sample may be checked, or the main may be re-chlorinated, the day following initial sampling. Also, the main may be released 18 hours after sampling resulting in earlier meter installation and faster service to customers, developers or builders. Income from new accounts is therefore more readily available, plus more rapid backfill, clean-up and less torch and barricade time. Finally, in the laboratory, fewer dishes and no tubes to wash and sterilize releases technicians for other work.

Materials costs vary between the two methods. Membrane Filter determinations cost approximately fifty cents per sample compared with five cents for each Standard Methods sample in our laboratory. However, we believe advantages gained from the Membrane Filter technique compensates for the cost difference.

Procedure Followed

We use the one-step HD method of Hajna and Damon, which permits us to detect only the coliform group. This is sufficient for us, because the presence of any of this group indicates possible contamination, with no particular need for differentiating which bacterium is responsible. Where this determination is required in some work, other Membrane Filter techniques are available.

Our procedure following new water main installation is as follows:

1. Main is loaded and rinsed.
2. Main is chlorinated, usually with

Table 4
Comparative Results: Membrane Filter vs Standard Methods Main Construction Samples vs Census Tract Samples 1958

Census Tract	MF Method - Main Projects Standard Method		Control Samples		Standard Method		Census Tract
	Date	Result	Date	Result	Date	Result	
71	5-28	—	6-2	—	6-4	—	71
17	5-30	—	6-4	—	6-8	—	17
11	5-29	—	6-4	—	6-5	—	11
1	5-29	—	6-4	[1]+	6-5	—	1
11	5-29	—	6-5	—	6-5	—	11
1	5-29	—	6-5	[1]+	6-5	—	1
34-43	6-9	— [3]+	6-10	—	6-17	— —	34-43
33-34	6-9	— —	6-10	—	6-17	— —	33-34
1	6-5	—	6-10	[1]+	6-12	—	1
53-54	6-10	— —	6-11	[2]+	6-18	— —	53-54
33-34	6-9	— —	6-12	—	6-17	— —	33-34
55	6-10	—	6-12	—	6-17	—	55
53-54	6-10	— —	6-12	—	6-18	— —	53-54
64-78	6-11	— —	6-13	—	6-18	— —	64-78
1	6-12	—	6-13	[1]+	6-20	—	1
10	6-12	—	6-16	—	6-20	—	10
1	6-12	—	6-17	[1]+	6-20	—	1
1	6-12	—	6-18	—	6-20	—	1
5	6-12	—	6-19	—	6-20	—	5
72	6-19	—	6-20	—	6-26	—	72
50	6-17	—	6-24	—	6-24	—	50
5	6-20	—	6-24	—	6-27	—	5
5	6-20	—	6-25	—	6-27	—	5
18	6-23	—	6-26	—	6-30	—	18
3	6-20	—	6-26	—	6-27	—	3
12	6-20	—	6-27	—	6-27	—	12
66	6-25	—	6-30	—	7-2	—	66
2	6-27	—	6-30	[2]+	7-7	—	2

[1] This was the only point available for control samples. Efforts were made to discover the source of positive samples at this location. When the difficulty was overcome (see samples for 6-18-58), the conformity with census tract samples was restored.

[2] No explanation for non-conformity; possible sample technique since subsequent samples were negative.

[3] Determined to be a result of sampling technique. Subsequent samples were negative.

liquid chlorine and chlorinator.
3. Main is rinsed and sampled.
4. Samples are in the laboratory by 4:30 pm and processed.
5. Samples are read by 9:00 am the following day. If positive, crews are dispatched to re-chlorinate the main. If negative, the main is released.

After a main is accepted for service, construction crews are released, valves are opened to circulate water and meters installed.

Other Membrane Filter Uses

We have used the Membrane Filter technique for occasional emergencies, including sickness, flooding and checking for suspected contamination. Fast service is rendered on complaints which improves public relations and protects the Water Department. Service is more rapidly restored from broken mains and the method serves to check repair crew disinfection procedures. We believe the capability of filing filters for future reference is a distinct advantage resulting from the use of Membrane Filters.

Practical instrumentation provides precision in determining . . .

BOD's for Plant Operation

by J. W. CLARK,
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EDITOR'S NOTE: In a previous paper (W&SW, April 1960), Mr. Clark detailed the principles and procedures involved in continuous BOD determination. Here, in a step-wise presentation, he describes practical application of the electrolysis equipment in determining raw sewage BOD. Involving no chemical techniques and capable of producing much precise information in one or two days, the method should be attractive to all sewage treatment plant operators.

■ THE BOD (biochemical oxygen demand) test is probably the best overall yardstick of sewage and industrial waste strength. It is a logical loading and design parameter of most sewage and industrial waste units, but its widespread application has been inhibited by the difficulties in its determination. The trained laboratory technician is discouraged by the results from operational BOD tests because of the low precision. Many of his other tests are chemical reactions that correlate to several significant figures. The many plant operators, in small and medium sized plants, that should be running BOD's don't because of discouragement in preliminary tries.

This lack of BOD information is reflected in higher design costs and lower operational efficiency. A consulting engineer goes into a community for the purpose of expanding its sewage treatment facilities and finds that many plants that keep records will faithfully report such things as temperature, flow, pH, gas produced, settleable solids, and other tests and recordable information, but if BOD's are reported at all, they will have the most gaps in the record. It is opposed to human nature to repeat routine operations whose results do not fit a logical pattern. The failure of the results to correlate unfairly implies a lack of personal skill. If the BOD test is to be used to its maximum, it must be reduced to a more mechanical operation with a higher degree of precision.

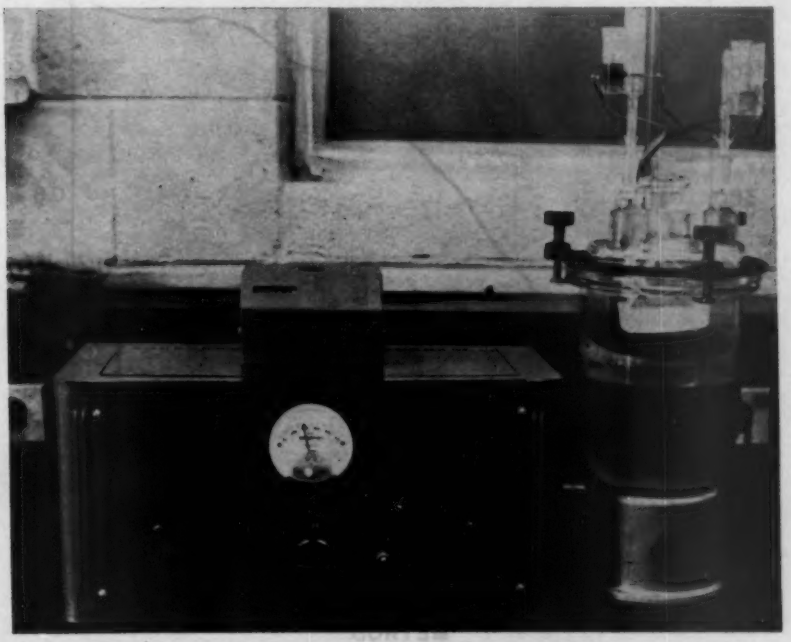

Fig. 1 BOD apparatus showing digester at right, mounted on magnetic stirring device. Totalizer, at left is mounted on power supply and amplifier.

Procedure

A new recording electrical method has been proposed[2,3] which reduces laboratory skill required and time consumed for BOD determination. A liter of undiluted sewage, digested in a closed system as illustrated in Figure 1, produces a reduction in result of the pressure loss, an elec- oxygen as digestion proceeds. As a

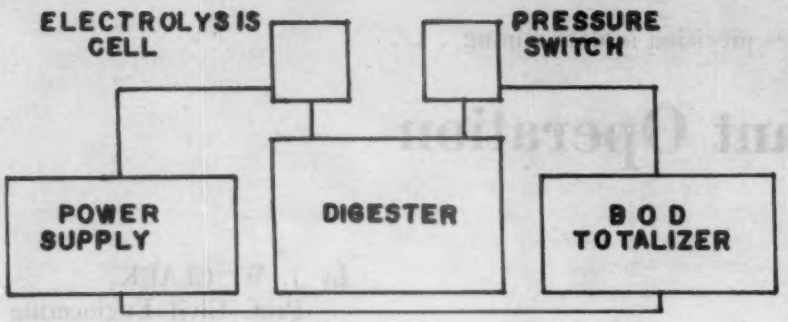

Fig. 2 SCHEMATIC LAYOUT of system

trolysis cell is energized, producing replacement oxygen. BOD is electrically totalized during digestion and may be read at any time on a water meter type dial. Digester contents are agitated by means of a magnetic stirring device. Figure 2 shows a schematic layout of the system.

Equipment

The digester used was a 2-liter resin reaction flask with standard top and ring. Any method of temperature control would be satisfactory as long as the temperature is maintained within one-half degree C.

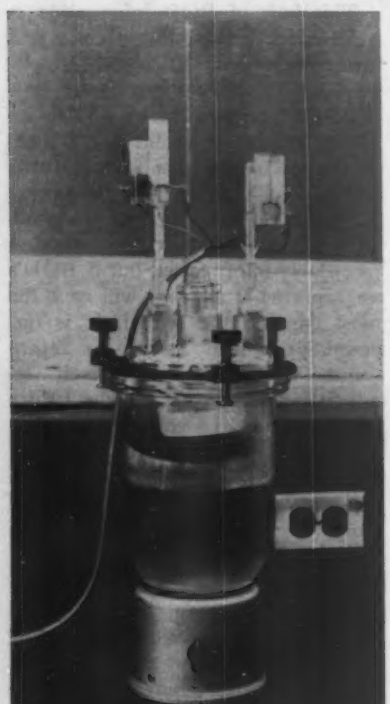

Fig. 3 CLOSE-UP OF DIGESTER showing connections to electrolysis cell and pressure switch. Note KOH container inside digester and thermometer projecting above cover.

A homemade plastic water bath was used with the temperature controlled by circulating water from a commercial water bath with refrigeration. The plastic allowed visual inspection through the sides and use of a magnetic stirrer under the bath. The electrolysis cell was made from plexiglass with two platinum wires as electrodes, Figure 3. The electrolysis cell was filled with 0.5 N sulfuric acid. A little distilled water must be added to the electrolysis cell after a few weeks of operation to replace the water disassociated for the oxygen.

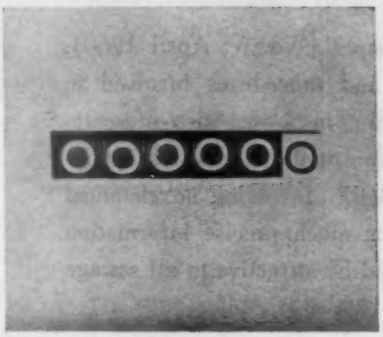

Fig. 4 TOTALIZER records current flow during electrolysis cell operation. Current flow is converted to BOD by multiplication factor.

The pressure switch was a U-tube with one side connected to the digester and the other side containing platinum electrodes so that an electrical connection would be made when the liquid contacted the electrodes. A 110v a-c relay connected the electrolysis cell to the power supply in the off position and disconnected the power supply from the electrolysis cell in the on position.

The electrical counting device was an inexpensive counter which recorded on or off time of an electrical machine or motor. It totalized electrolysis cell operation in hours and tenths of hours, Figure 4. A similar counter could be made to read directly in BOD. BOD was converted from hours by a multipli-

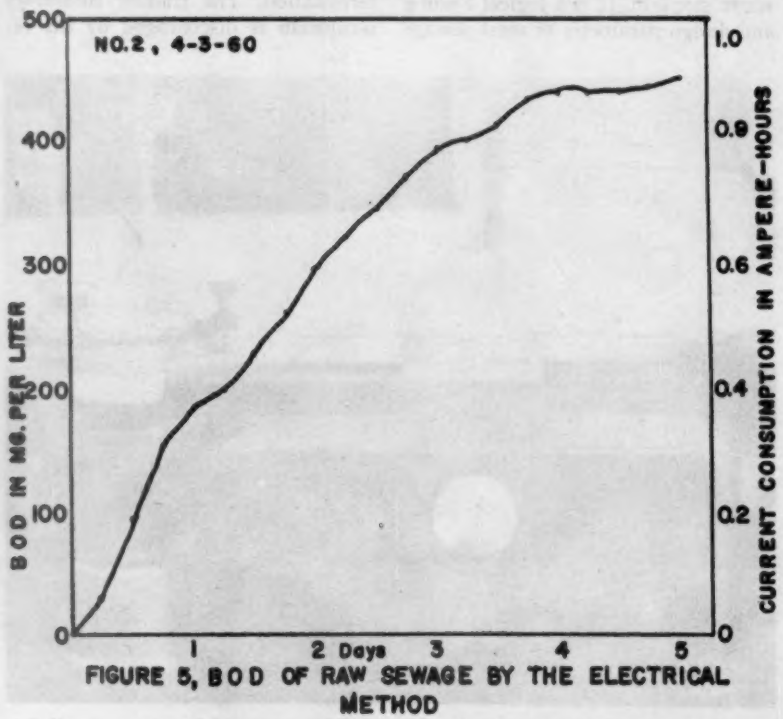

FIGURE 5, BOD OF RAW SEWAGE BY THE ELECTRICAL METHOD

FIG. 5 CURVE SHOWING BOD of raw sewage as obtained by electrical device.

cation factor related to the power setting of the power supply.

Amperes measure the rate at which electrons flow and, therefore, the rate at which electrolysis takes place. The coulomb is the unit of quantity of electricity. A current of one ampere flowing for one second carries one coulomb of electricity past a point in the system. A coulomb measures a definite number of electrons. A Faraday is 96,500 coulombs. The Faraday is the charge on 6.023×10^{23} electrons, (Avogadro's number). One Faraday will deposit one gram-equivalent weight of an element—107.88 grams of silver, 8.00 grams of oxygen, etc.

The power supply for these experiments was set to deliver 100.7 milliamperes, equivalent to 30 mg per hour of oxygen at maximum demand. In converting a dial reading to BOD, the number of hours was multiplied by 30. Using a one liter sample, with a dial reading of 8.3 at the end of 5 days, the BOD would be 250 mg/l.

The potassium hydroxide boat suspended from the center of the digester contained 30 ml of 30% KOH solution. The purpose of the potassium hydroxide solution was to react with the carbon dioxide given off by the bacteria.

A plastic covered bar magnet ⅜" x 1⅜", in the bottom of the digester, was rotated by a standard magnetic mixer and disturbed the surface sufficiently for digester aeration.

Preliminary tests on synthetic sewage and pure substances agree within 5% of the calculated 5-day carbonaceous BOD.

Conclusions

This method of BOD determination should find wide application in sewage and industrial waste plant operation. It provides the plant operator with an easy method of determining BOD without resorting to chemical techniques. Tests on domestic sewage have been run, Figure 5 and the speed with which undiluted sewage samples progress indicates that much valuable BOD information may be obtained in one or two days.

Acknowledgments

This is an outgrowth of a study supported by a research grant from the National Institutes of Health, U. S. Public Health Service.

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Practical Field Use and Convenience Feature a . . .

Simplified Test for Hexavalent Chromium

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■ While the method for the determination of hexavalent chromium described in Standard Methods[1] has been found satisfactory for routine laboratory use, there is a definite need for a test utilizing both stable reagents and stable permanent standards. While being a modification of the standard method, the method devised has the advantage of using a single stable reagent in powder form instead of relatively unstable liquid reagents. In addition, permanent liquid standards have been prepared for this method.

Reagent

The hexavalent chromium reagent is prepared as follows:

(1) Grind together 0.25 g 1,5-Diphenylcarbohydrazide and 9.75 g Tartaric Acid using a mortar and pestle. Continue grinding until the powder appears completely uniform (about two or three minutes).

(2) Store in any convenient plastic container. Colored containers are not necessary.

Procedure

To fifty (50) ml of sample or fifty (50) ml of a suitable dilution add approximately 0.1 g of the reagent powder and shake or stir vigorously to dissolve the reagent. Allow at least five (5) minutes for full color development then measure the absorbance in a spectrophotometer at 540 mμ in a filter photometer using a green filter, or compare with a series of permanent standards. While 0.1 g of the reagent is all that is necessary to properly perform this test, reagent in excess of this amount will not interfere with this test. Table 1 compares the results of tests conducted with various amounts of reagent. Results obtained with this modification are identical with those obtained with the standard method, see Table 2.

Table 1
Comparison of Varying Amounts of Reagent

Prepared Test Solution Containing Hexavalent Chromium (ppm)	Amount of Reagent (gram)	Test Result:* Hexavalent Chromium (ppm)
1.000	0.1	1.000
1.000	0.1	1.000
1.000	0.1	0.996
1.000	0.2	1.000
1.000	0.2	1.011
1.000	0.2	1.000
1.000	0.3	0.996
1.000	0.3	1.000
1.000	0.3	1.000

*Typical series of data.

Table 2
Typical Series

Hexavalent Chromium (ppm)	By Standard Method (ppm)	By Reagent Powder Modification (ppm)
0.50	0.52	0.50
1.00	1.00	1.02
1.50	1.46	1.47
2.00	1.89	1.90
2.50	2.43	2.42
3.00	2.98	2.95

Color Standards

Permanent standards are readily prepared from two bacteriological stains commonly present in Water and Sewage Laboratories. Prepare crystal violet and safranin stains as directed for the Gram Stain Technic, Standard Methods[1].

Ammonium oxalate crystal violet: Solution A: Dissolve 2.0 g crystal violet, certified, in twenty (20) ml 95% ethyl alcohol. Solution B; Dissolve 0.8 g ammonium oxalate in eighty (80) ml distilled water. Mix solutions A and B in equal parts. Safranin: Dissolve 2.5 g of safranin, certified, in 100 ml 95% ethyl alcohol and add them to distilled water. Dilute 1.4 ml of the crystal violet stain to a final volume of fifty (50) ml using distilled water. To approximately ten (10) ml of distilled water add the amounts of each of the two stains indicated in Table 3 and dilute to a final volume of fifty (50) ml with distilled water.

Discussion

This modification of the standard method has been found superior to the standard method in both convenience and stability of reagent. While 1,5-Diphenylcarbohydrazide in its usual formulation spoils rapidly even when kept refrigerated, the powder reagent used in this modification is stable indefinitely, providing only that it be kept dry. When used in the field as a screening technique, it is only necessary to carry reagent powder and a small glass vial.

The permanent standards are absolutely stable. Standards prepared as indicated have been used in this laboratory for one and a half years. Periodic checks of these standards using a spectrophotometer have indicated that no change has taken place in them even though the standards have not been protected from light.

Reference

Standard Methods for the Examination of Water, Sewage, and Industrial Wastes, APHA, AWWA & WPCF, New York (10th ed., 1955).

Table 3
Standard Formulation

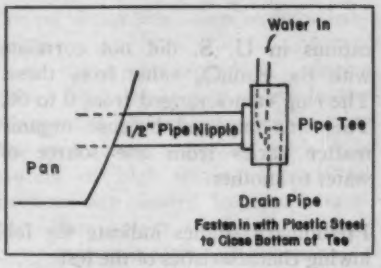
Hexavalent Chromium* (ppm)	Crystal Violet Dilute (ml)	Safranin (drops)
0.5	0.4	1
1.0	0.8	2
1.5	1.2	3
2.0	1.6	4
2.5	2.0	5
3.0	2.4	6
3.5	2.8	7
4.0	3.2	8

*Equivalent

A COPPER-FREE WATER STILL FOR THE SHOE-STRING LABORATORY

by GEORGE A. RHAME, Univ. of North Carolina

■ BEING IN PROCESS of constructing a laboratory financed on the shoe-string basis the writer was considerably bothered by the problem of a source of distilled water suitable for biological work. The solution described here works quite well.



Basis of this water still is a modestly priced ($7.95) electric frying pan of all-aluminum construction bought at a 5 and 10c Store, with its lid. (Be sure the pan, at least, is solid aluminum.) Pan may be round or square—mine is square, but I think a round one would be better.

Begin construction by removing the handle, then bore a hole in the side of the pan to take a ½ in. pipe nipple, 4 inches long. Make the center of the hole about one inch from the inside bottom of the pan. Don't thread the hole, just screw the nipple in so that it will be horizontal when the pan is set up on its legs. Screw a common pipe Tee onto the nipple; set a small drain pipe into the bottom of the Tee with plastic steel as shown in the drawing. Make the inside end of the drain pipe level with the top invert of the ½ in. nipple. Closure of the bottom of the Tee must be water tight. Drain may be ¼ in. pipe or tubing.

Before going to work on the lid, obtain a glass laboratory condenser (exact type does not matter). Select a piece of glass tubing for the steam pipe of such outside diameter as to fit closely inside the condenser steam inlet *without binding*. This eliminates a major breakage problem. Arrange a support for the condenser suitable to the materials at hand. Set the condenser about 18" inches above the top of the pan.

Back to the fry-pan lid. Remove the knob; use the resulting rivet hole for the steam outlet. Obtain a piece of iron pipe, or electrical conduit, about 3 inches long. Inside diameter should be about 1/16 in. greater than the outside diameter of the glass steam pipe. Seal the end of this short pipe to the lid with plastic steel, centering it over the rivet hole.

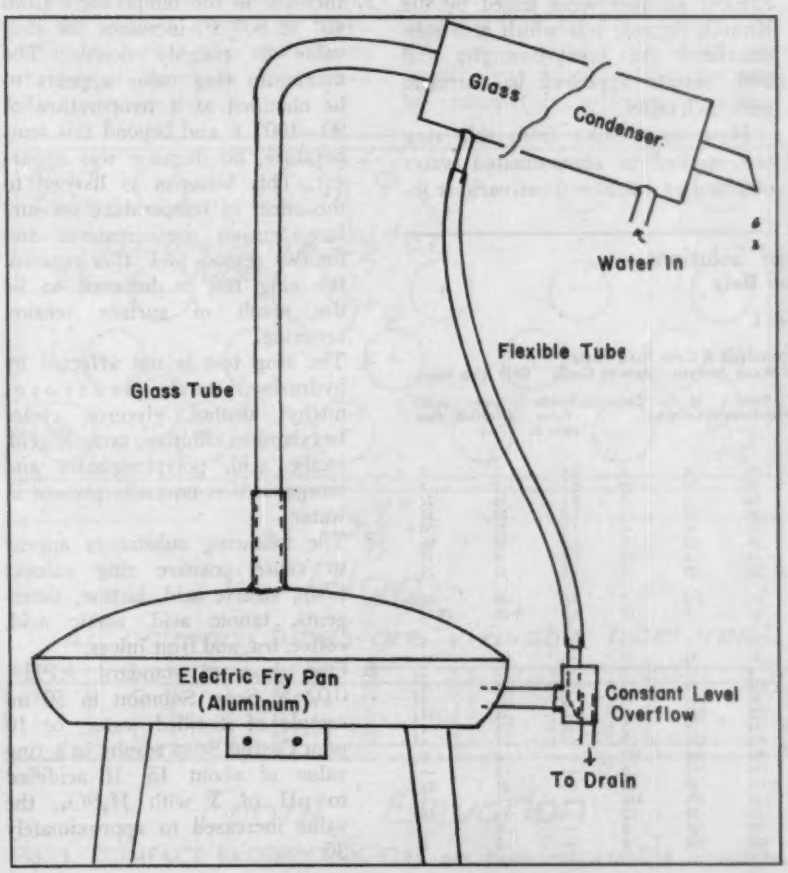
Bend the steam pipe so that the condenser will have a suitable angle for discharging condensate. Wrap the lower end of the steam pipe in some soft cotton cord, and insert into the stand-pipe on top of the lid. Place the condenser on the other end of the steam pipe and fasten it to the support.

Bonding the lid to the body of the pan is not advisable, since it will occasionally be necessary to remove accumulated scale from the pot. Arrange clamps suitable to the shape of the lid. It will probably be necessary to fill the groove between pan and lid with soft cotton cord.

Be careful when connecting the condenser cooling water outlet to the constant level device to use a good grade of rubber or plastic tubing. The water will be quite hot. Put a short piece of glass tube at the end entering the Tee.

Because of the simple off-on thermostats in these fry-pans it will probably be found that the still surges badly in operation. Control this by connecting a light socket *in series* in the power supply as shown in the wiring diagram. Try different light bulb sizes until you find one which passes sufficient current to heat the still gently and continuously. Use just enough water into the condenser to condense all of the steam.

Boy, you're in business!



The "Crits Organic Ring Test"

A Simple Test for Trace Organic Substances in Water

G. J. Crits
Asst. Technical Director
Cochrane Corporation.

■ WHEN WATER IS shaken vigorously in a glass container, sometimes a foam at the surface develops which is indicative of organic substances, such as amines, detergents, stearates, etc. However, in most cases, these substances exist in such low concentrations that no foam develops, in which case another physical phenomenon has been observed which is useful in detecting the presence of such organic substances in water. This phenomenon is characterized by the formation of a cylindrical film on the glass wall above the shaken water sample. Actually, immediately following vigorous shaking and draining, an "annular ring" forms at the surface of the water and appears to rise along the surface of the glass container until it disappears at a height dependent on the contamination in water. The greater the contamination, the greater is the height of this ring. For instance, no such ring forms with most well waters which are relatively free of organic contamination; but with surface waters, particularly from contaminated rivers, various positive values were obtained.

The test is best performed in a glass stoppered 100 ml graduated cylinder which is filled only to the 50 ml mark. The graduate is shaken up and down briskly several times and after stopping, the ring (if any) is observed to travel upwardly along the wall until it disappears from sight. The height of travel is read in ml from the calibrated cylinder. The test procedure is repeated several times until the maximum value is obtained.

The simple test was first proven by application to activated carbon filtration studies. The influent water had a ring value of 18; but the effluent measured zero at the beginning and for most of the run. At the end, the ring value gradually increased and samples were taken at values of zero, six, eleven, and finally eighteen. Simultaneously, the effluent samples were tested by the $KmnO_4$ organic test which also substantiated the break-through; and both results appeared to correlate with each other.

However, results from this ring test applied to contaminated water obtained at random from various locations in U. S. did not correlate with the $KmnO_4$ value from these. The ring values ranged from 0 to 60. This was expected because organic matter varies from one source of water to another.

Preliminary studies indicate the following characteristics of the test:

1. Adjustment of the pH of the sample to approximately 2 to 3.5 with H_2SO_4 appears to accent the ring value—roughly doubling the value.
2. Small alkali additions do not alter the ring value.
3. Increase in the temperature from 40° to 80° F, increases the ring value to roughly double. The maximum ring value appears to be obtained at a temperature of 90—100° F and beyond this temperature, no increase was apparent. This behavior is likened to the effect of temperature on surface tension measurements and for this reason, and other reasons, the ring test is believed to be the result of surface tension lowering.
4. The ring test is not affected by hydrazine, starch, dextrose, methyl alcohol, glycerol, cyclohexylamine, chlorine, tartaric acid, oxalic acid, polyphosphates and inorganic ions normally present in water.
5. The following substances appear to cause positive ring values: Soap, stearic acid, lactose, detergents, tannic acid, acetic acid, coffee, tea, and fruit juices.
6. One drop of standard APHA 0.02 N Soap Solution in 50 ml sample of distilled water, or 10 ppm Castile Soap results in a ring value of about 15. If acidified to pH of 3 with H_2SO_4, the value increased to approximately 30.

Preparations of Solutions
Operation Data

Table I

Partial List of Water Analysis X Crits Ring Tests

City & State	Sample Source	Partial Water Analysis —ppm as $CaCo_3$ Total Anions or Cations	Total Hardness	M. O. Alkalinity	Chlorides	$KmnO_4$ Value ppm O_2	Crits Ring Value un acidified	acidified
Levittown, Pa.	Open Shallow Well	118	106	38	6	0.5	1	2
Wil., Del.	Well—Shallow	173	76	98	22	0.5	2	4
Paulsboro, N. J.	River—after coag.	76	52	13	9	0.7	16	22
Huntsville, Ala.	Tenn. River	87	64	50	13	1.0	22	33
Wilsonville, Ala.	After filters-surface	83	72	43	3	1.7	32	50+
Wilsonville, Ala.	City Water	127	126	123	0	1.5	32	55
Pittsburgh, Pa.	City Water	85	66	6	10	1.8	9	17
Holyoke, Mass.	City Water	43	34	20	10	1.9	13	25
Ninette, Manitobe	Well Water—contaminated	392	330	310	9	4.0	45	60+
Port Wentworth, Ga.	Surface	67	50	37	13	4.0	9-10	17-18
Reading, Ohio	Municipal Water Plant	536	78	35	159	—	4	8
Richmond, Va.	City Water	57	36	33	1	—	7	11
Frackville, Pa.	Artesian Well	7	6	3	0	—	2	2
Steubenville, Ohio	Pri. Artesian Well	269	218	98	7	—	9	13
Woosocket, R. I.	Sand Packed Well	63	44	35	4	—	1	1
Aurora, Ontario	Well	230	202	220	0	—	6	11
Sitka, Alaska	Filter Plant Effluent	23	14	8	3	—	1	1
Fort Dodge, Iowa	City Water	566	410	375	7	—	1	1
Milford, Mich.	Well	466	450	280	137	—	3	5
Cali, Columbia, S. A.	Pri. Artesian Well	206	170	190	0	—	1	—
Linden, N. J.	Private Reservoir	158	110	80	32	—	21	33
Whetland, Pa.	Well Water	759	18	275	476	—	1	—
Elktron, Md.	Elk Creek	87	70	28	12	—	11	15
Yorklyn, Del.	Artesian Well	60	60	28	0	—	2	—
Rock Falls, Ill.	Well—1550' deep	336	320	303	4	—	2	2

Block for Incubation of Gas Tubes

by A. A. HIRSCH
Water Purification Superintendent
Dept. of Water and Sewerage
Shreveport, La.

■ ROUTINE BACTERIOLOGICAL examinations of samples from various points in a water supply system can be simplified by the use of a storage block during incubation that permits rapid scanning of the individual gas tubes. The design described here may be inspected at a single glance on the incubator shelf even without handling.

In the usual procedure, samples taken from significant points in the system are planted in tubes containing some form of lactose broth. For waters of high quality five 10-ml portions are planted from each sample. For waters of lower quality, a geometrical series of dilutions is used. If coliform bacteria are present gas collects and is observed inside an inverted vial within the broth tube. Identification is confirmed by noting if gas also forms when some of the fermented material from the primary broth tube is inoculated into an inhibitory secondary medium, such as brilliant green bile broth. During incubation tubes are retained either in a basket or in a block drilled to receive them.

Fig. 2. BLOCK FOR Incubating gas tubes.

Special Block

The block illustrated in Fig. 1, and photographed in Fig. 2, provides the following features:

1. Room is provided for all primary gas tubes planted daily; in this particular case three rows of holes for 5 tubes of 10 ml portions each from the following sources: (R) superchlorinated raw plant influent, (S) settled water from basins, and (F) finished water to the distribution system. A fourth row of smaller holes hold infrequent confirmatory tubes from the first two sources.

2. Tubes are spaced by overlapping the three rows as shown in the plan and front elevation so that all inverted vials can be viewed simultaneously from the front without obstruction of vision. All 15 of the primary gas tubes in this case can be observed in a single sweeping glance, thereby saving time in sorting.

3. A white, matte finished plexiglas tag nailed to one end of the block permits any necessary identification marks, such as dates to be readily written in pencil and easily erased upon completion of the test.

Construction

The tube storage block illustrated was cut from a nominal 2 in. x 8 in. piece of cypress. Holes, 1 in. and ⅞ in. in diameter, spaced as shown were drilled short of penetrating the bottom by ¼ in. A 1¼ in. x 6 in. piece of matte finished plexiglas, 1/16 in. thickness, was nailed to the end of the block with round headed plated finishing nails.

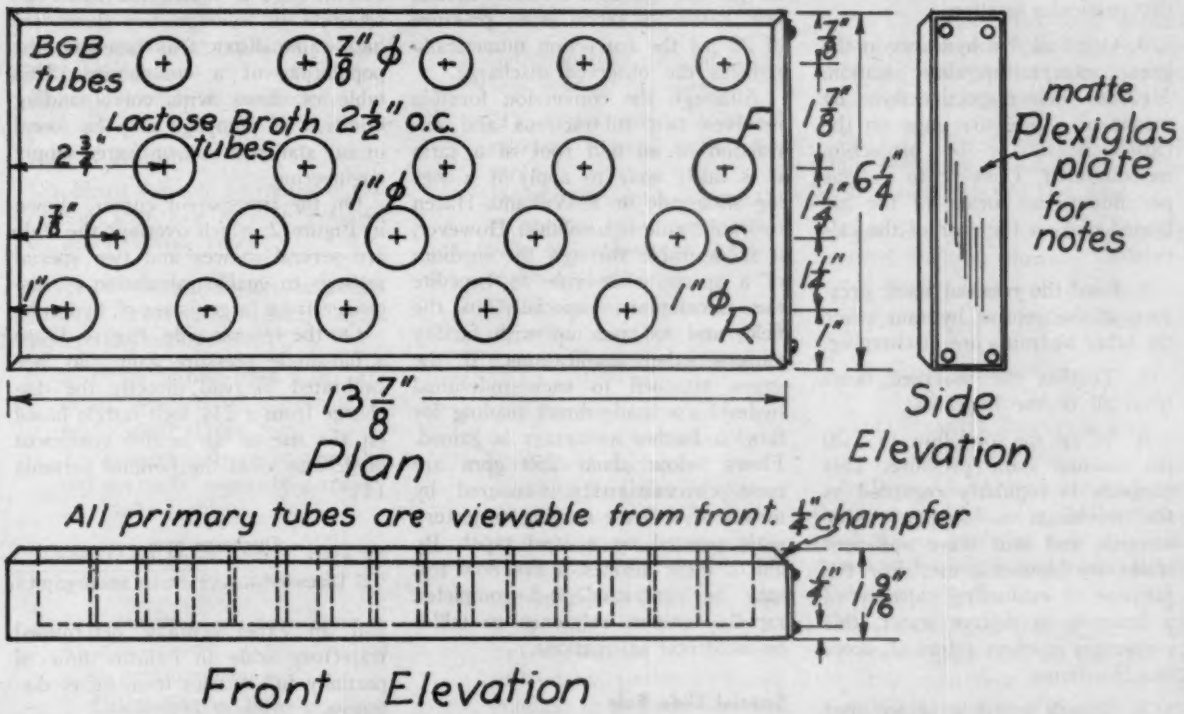


Fig. 1. COMPACT BACTERIOLOGICAL gas tube rack enabling inspection at a glance.

Fire Flow Slide Rule

by A. ADLER HIRSCH

Water Purification Superintendent, Department of Water & Sewerage, Shreveport, Louisiana.

■ FIRE FLOW TESTS made at strategic locations, such as in the high use districts, near industrial consumers, and at the outskirts of a water utility, enable an operator to check conveniently the adequacy of his distribution system by a direct experimental method[1]. Procedure for conducting such tests was described almost four decades ago[2] and is now fairly well known.

Fire Flow Test

Essential steps in a typical fire flow survey are as follows:

1. Select a group of three to eight hydrants for test.

2. Determine the static pressure at a central hydrant or other tap before starting the test; this value is the normal static pressure at that particular location.

3. Open all fire hydrants in the group except the static station. Measure their respective flows by means of a pressure gage on the closed nozzle or by projection measurement. Convert to gallons per minute by means of the calibrated dial on the rear of the calculator.

4. Read the residual static pressure at the central hydrant while the other hydrants are discharging.

5. Totalize the observed flows from all of the hydrants.

6. Adjust the total flow to a 20 psi residual static pressure. This pressure is regularly regarded as the minimum to supply engine streams and still leave sufficient water for domestic use. For the purpose of evaluating capacity of a network to deliver water, this correction in effect refers all flows to a like datum.

7. Consult schedule of required flows to determine the adequacy of the system for delivery at this point.

8. Move to the next test location and repeat the above steps.

Conversion Formula

The formula used for adjusting the observed flow to that expected at a 20 psi residual static pressure is based on the head vs. quantity exponent in the Williams Hazen equation, giving

$$\text{Flow, gpm}_{\text{20 psi}} = \text{Flow, gpm}_{\text{observed}} \times \left(\frac{\text{Normal static, psi} - \text{20 psi}}{\text{Normal static, psi} - \text{Actual Static, psi}}\right)^{0.54}$$

If the observed static pressure during the test exceeds 20 psi the adjusted flow is somewhat greater than the quantity as measured. At 20 psi the correction factor cancels out. Below an actual static pressure of 20 psi the correction numerically reduces the observed discharge.

Although the conversion formula involves two subtractions and extraction of an odd root of a ratio it is fairly easy to apply if a log-log slide rule or a Williams Hazen hydraulic rule is available. However, it is desirable through the medium of a special slide rule to expedite the calculations, especially in the field, and to open up with facility various other applications. If the gages attached to each individual hydrant are made direct reading for flow[3] a further advantage is gained. Flows below about 250 gpm are most conveniently measured by means of a direct reading trajectory scale painted on a steel tape[4]. By aid of these devices, a fire flow test may be conducted and completed rapidly without reference to tables or incidental calculations.

Special Slide Rule

This slide rule, illustrated in Figure 1, was designed to eliminate entirely all incidental calculations when adjusting observed flows to the usual 20 psi residual static pressure basis. On the top is a fixed scale for flow, gpm, marked 1, while the slide, labelled 2, carries a graphical plot of the function

$$\left(\frac{\text{Normal static, psi} - \text{20 psi}}{\text{Normal static, psi} - \text{Actual Static, psi}}\right)^{0.54}$$

for the range in values of these variable likely to occur in practice.

On the bottom stock, numbered 3, is a schedule of residential district flow requirements as recommended by the National Board of Fire Underwriters[5] to aid in interpreting the findings and in judging whether the network is adequate for protection at the point tested. Also along the bottom edge is shown the N.B.F.U. schedule of average fire flows for high value districts as based on the population of a community. This table of flows with corresponding duration of pumpage may be found in any standard text on water supply engineering.

On the transparent cursor, shown in Figure 2, which overlays the slide are several indices and two special settings to enable calculation of discharge from larger sizes of hydrants.

On the reverse side, Figure 3, are a fac-simile pressure gage dial face calibrated to read directly the discharge from a 2½ inch nozzle based on the use of an orifice coefficient of 0.90 to yield the familiar formula (1)

$$\text{Discharge, gpm} = 27\ \text{Diameter}^2_{\text{inches}} \sqrt{\text{Pressure reading, psi}}$$

and an experimentally determined trajectory scale to indicate flow of partially full nozzles from offset distances.

The calculator described above will

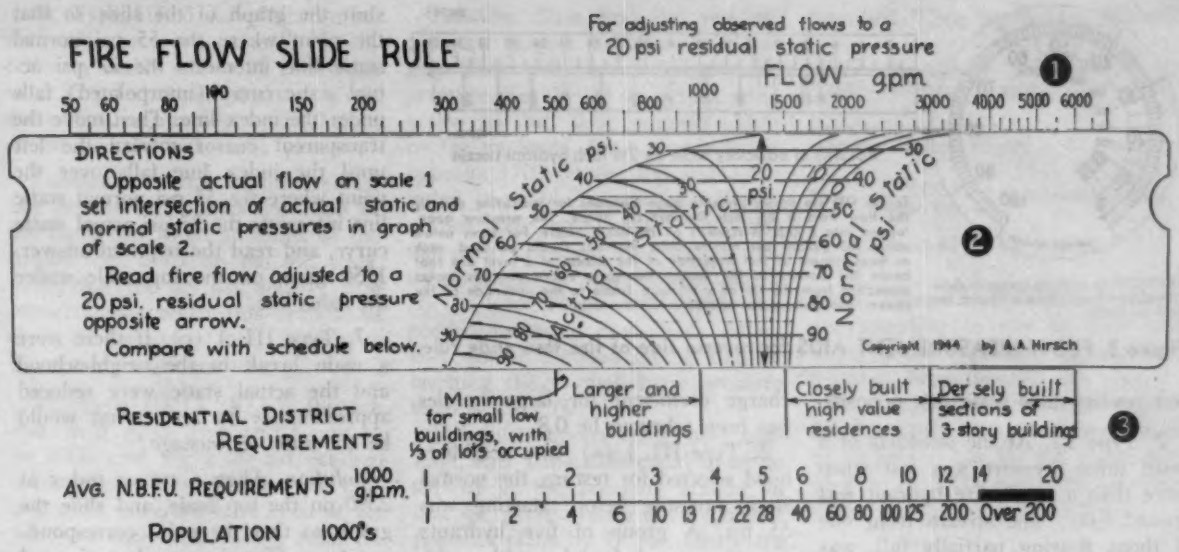

FIRE FLOW SLIDE RULE
For adjusting observed flows to a 20 psi residual static pressure
FLOW g.p.m.
DIRECTIONS
Opposite actual flow on scale 1 set intersection of actual static and normal static pressures in graph of scale 2.
Read fire flow adjusted to a 20 psi. residual static pressure opposite arrow.
Compare with schedule below.
Normal Static psi.
Actual Static psi.
Copyright 1944 by A.A. Hirsch
RESIDENTIAL DISTRICT REQUIREMENTS
Minimum for small low buildings, with 1/3 of lots occupied
Larger and higher buildings
Closely built high value residences
Densely built sections of 3-story buildings
AVG. N.B.F.U. REQUIREMENTS 1000 g.p.m.
POPULATION 1000's
Over 200

Figure 1. FRONT FACE of fire flow slide rule.

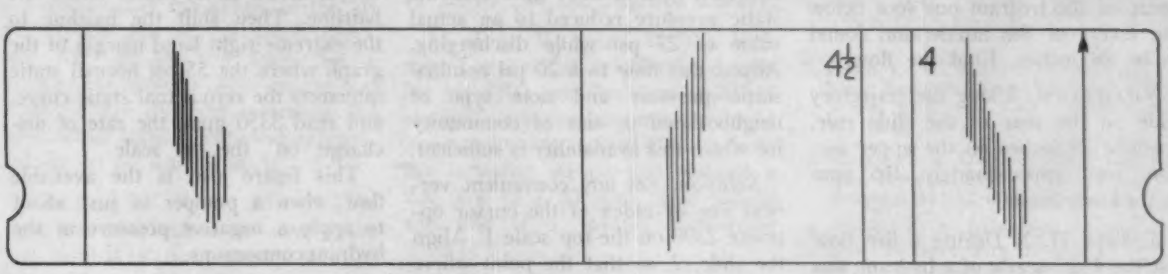


Figure 2. TRANSPARENT Cursor for fire flow slide rule.

solve expeditiously five types of problems, as illustrated by the 13 separate examples explained below. Other basic values of this technique will undoubtedly be developed.

Types of Problems

Problems solvable by means of the fire flow slide rule may be grouped into the following types:

Type I. Determination of actual discharge from fire hydrants with standard 2½ inch nozzles

1. Flows jetting from a fire hydrant, found directly from pressure gage readings
2. Discharges from a partially full nozzle by means of a trajectory scale

Type II. Use of other sizes of fire hydrant nozzles

1. Calculation of flow from a 4 inch nozzle using residual static pressure data
2. Calculation of flow as above for a 4½ inch nozzle

Type III. Variations between pressures and flows

1. Determination of flows at various residual pressures
   (a) Adjustment to a 20 psi standard residual static pressure
   (b) Adjustment to some other residual static pressure
   (c) Adjustment to a zero residual static pressure
2. Determination of residual static pressures to be expected at a given flow and normal static pressure
   (a) Determination of residual pressure corresponding to a required discharge
   (b) Determination of the residual pressure at a given flow corresponding to a change in normal pressure
3. Determination of normal static pressures
   (a) Calculation of the normal static pressure corresponding to a given flow and assigned residual actual static pressure
   (b) Determination of normal static needed for a given flow to reduce the actual static pressure to zero

Type IV. Calculation of booster pump discharge pressure needed to bolster an insufficient fire flow

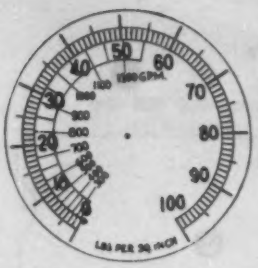
Type V. Calculation of pipe sizes required for fire flows

1. Simple case of direct reinforcement by means of parallel line
2. Sizing of new lines.

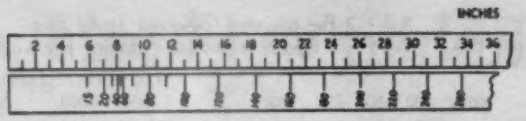
Illustrative Examples and Solutions

1. Type I,1. A pressure gage on the closed nozzle of a fire hydrant reads 25 psi while its twin 2½ inch nozzle is flowing during a test. What is its rate of flow?

Solution. From the fac-simile of a pressure gage dial, on the rear of the slide rule, note that 25 on the pounds per square inch scale is opposite 845 approximately on the di-



DIVISIONS on pressure gauge to show rate of flow directly from a 2½ inch fire hydrant nozzle.



RULING of trajectory scale for 2½ inch hydrant nozzle

To the left are shown pressure gage divisions for indicating directly the flow from a 2½ inch fire hydrant nozzle. The pressure gage, tapped into a cap, is screwed on the other nozzle. For flows below about 250 gallons per minute other methods should be used, such as measurement of the projection of the stream at a level one foot below the bottom of the nozzle. The scale above converts inches projection from the tip of a 2½ inch nozzle to the underside of the stream into gallons per minute.

Figure 3. FLOW MEASUREMENT AIDS for reverse side of fire flow slide rule.

rect reading flow scale just opposite.

2. Type I,2. At the outskirts of a small town pressure was lost when more than a single fire hydrant was opened fully. The stream from one of them, flowing partially full, was measured out to the stream from a point on the hydrant one foot below the invert of the nozzle and found to be 28 inches. Find the flow.

Solution. Using the trajectory scale on the rear of the slide rule, opposite 28 inches on the upper section, read approximately 216 gpm on the lower scale.

3. Type II, 1. During a fire flow test the 4 in. nozzle of a hydrant was opened, giving an actual static reading at the other nozzle which was capped of 30 psi. What was the flow?

Solution. The calibrated pressure gage used in problem 1 indicates that for a 2½ inch nozzle the flow would have been about 925 gpm. Set the line marked 4 in. on the transparent cursor opposite 925 on the top scale. Opposite the arrow at the right hand end of the cursor read 2100 gpm on the top scale.

4. Type II, 2. If the active nozzle in the problem above were 4½ inches, what would the flow have been?

Solution. Proceed as previously, except that the 4½ in. line on the cursor is set opposite 925 on the top scale. Opposite the arrow near the right hand end of the cursor read 2670 gpm, the required answer.

Use of the orifice formula with large size hydrant nozzles is not considered accurate, as the discharge coefficient decreases between 0.9 and 0.7 and is subject to variations. However, this method is still useful if recognized as an approximation. On the cursor of the slide rule the discharge coefficient for large nozzles has been taken to be 0.8.

5. Type III, 1 (a). In a neighborhood selected for testing, the normal static pressure before starting was 55 psi. A group of five hydrants was then opened and together delivered a total of 2390 gpm with the static pressure reduced to an actual value of 27 psi while discharging. Adjust this flow to a 20 psi residual static pressure and note type of neighborhood or size of community for which this availability is sufficient.

Solution. Set any convenient vertical line or index of the cursor opposite 2390 on the top scale 1. Align the slide, 2, so that the point where the 55 psi normal static line intersects the 27 psi actual static curve (interpolate) in the graph falls under the index. Opposite the top arrow of the 20 psi line of the graph read 2660 gpm on the top scale, giving the required answer. Reference opposite the bottom arrow of the slide to the interpretative scale 3 below shows that this flow is ample for high class, closely built residential districts. Transferring this flow of 2.7 thousand gpm to the very bottom scale shows that the commercial district of a community having about a 7500 population would ordinarily be satisfied.

The foregoing example illustrates the basic problem for which this calculator was conceived. Other types of applications have evolved from the pertinency of the graph of the ratio of differential pressures raised to the 0.54 power to various hydraulic problems.

6. Type III, 1 (b). What would the observed flow have been if the actual static in the previous problem were 35 psi?

Solution. As above, set a cursor line at 2390 on the top scale, and shift the graph of the slide so that the point where the 55 psi normal static line intersects the 27 psi actual static curve (interpolated) falls under the index line. Then move the transparent cursor toward the left until the index line falls over the point where the 55 psi normal static line intersects the 35 psi actual static curve, and read the required answer, 1950 gpm, on the top scale under the index line.

7. Type III, 1 (c). If there were a main break in the neighborhood and the actual static were reduced approximately to zero, what would be the rate of wastage?

Solution. Align a cursor index at 2390 on the top scale, and slide the graph so that the point corresponding to a 55 psi normal static and 27 psi actual static comes under the hairline. Then shift the hairline to the extreme right hand margin of the graph where the 55 psi normal static intersects the zero actual static curve, and read 3350 gpm, the rate of discharge, on the top scale.

This figure also is the available flow when a pumper is just about to apply a negative pressure at the hydrant connections.

8. Type III, 2 (a). In the preceding problem, what must the residual actual static be reduced to in order to permit a flow of 2900 gpm?

Solution. Set up the slide rule as before, with the cursor at 2390 on the top scale and passing through the graph point of 55 psi normal static and 27 psi actual static. Then slide the cursor to 2900 on the top scale and on the graph along the 55 psi normal static line read the intersection with the 13½ psi residual pressure curve, the required answer.

9. Type III, 2 (b). If the normal pressure in Problem 1 were raised to 70 psi what would the residual pressure become to maintain flow at the same rate, viz., 2390 gpm?

Solution. Again set the slide rule with the cursor on 2390 of the top scale and the graph shifted so that the point corresponding to 55 psi normal static and 27 psi actual static falls under a hairline. Glance down the hairline to its intersection with the 70 psi normal static line, and note the intersection there with the 30 psi residual actual static curve, giving the required answer.

10. Type III, 3 (a). What must the static pressure normally be in order to enable a flow of 2000 gpm at a 25 psi residual pressure, given a fire flow requirement of 2660 gpm at 20 psi residual static pressure?

Solution. Set the 20 psi residual line on the graph opposite 2660 of the top scale. Align an index of the cursor with 2000 on the top scale. Note that the 25 psi actual static curve crosses under this vertical at about 32 psi normal static level, giving the required answer.

11. Type III, 3 (b). If the fire flow in a given area was found to be 2000 gpm for a 20 psi residual static pressure, what must the normal static pressure have been at the time of a main break during which the flow was estimated at 3000 gpm?

Solution. Set the arrow of the 20 psi vertical line of the graph opposite 2000 on the top scale. Set a cursor line opposite 3000 on the top scale; where this line intersects the zero actual static curve read approximately 40 psi normal static.

12. Type IV. A fire flow of 1300 gpm was obtained in an area where the normal static pressure was 50 psi with pumping station pressure at 70 psi. In order to obtain a required 1700 gpm fire flow to what pressure must the station pressure be boosted?

Solution. First find the residual pressure needed to obtain a 1700 gpm flow with the existing static pressure. Set the 20 psi actual static arrow of the slide opposite 1300 on the top scale. Set a cursor index opposite 1700 on the top scale; the index is noted to cross the 50 psi normal static line at about 1 psi residual static pressure. This means that an additional pressure differential of $20 - 1 = 19$ psi will supply the needed increased flow. This difference can be obtained just as well by boosting the normal static pressure to $50 + 19 = 69$ psi.

Other conditions being held constant, this same differential must be applied at the pumping station so that the whole system is on a higher pressure plane by 19 psi. Hence the station pressure must become $70 + 19 = 89$ psi, the required answer.

13. Type V, 1 and 2. If a high valued residential neighborhood calling for 2500 gpm fire flow at 20 psi residual static pressure was developed in a subdivision located 8000 ft from the pumping station and showed a fire flow of 1730 gpm, what should the size of a parallel reinforcing main be?

Solution. The slide rule is assumed to have been used as in Problem 1 to calculate the fire flow as existing and to determine the range in values required for a residential district as described. Then proceed as follows:

Deficit in fire flow =
$2500 - 1730 = 770$ gpm

Existing pressure drop =
Station (assume 80 psi) $- 20 = 60$ psi

$$\text{Slope} = \frac{60 \text{ psi}}{8000/100} \times 2.31 \text{ conversion factor}$$

$= 1.73$ ft water per 100 ft length

From Hazen and Williams tables, corresponding to rate of flow and slope, obtain pipe size slightly over 8 inches, hence use 10 inch pipe.

If a single new pipe were needed for the whole flow, the slope would be as before, but for the entire rate of flow of 2500 gpm; the required pipe diameter becomes 14 inches.

References:

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Flow Velocity in Partly Filled Pipes

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■ IT IS IMPORTANT, for a variety of purposes in the sanitary engineering field, to be able to calculate velocity and flow conditions in sewers running less than full. The equation which has come to be known as Manning's is most commonly used for this purpose. This equation rests upon the classical assumption that velocity can be calculated as a function of R, S, and a friction coefficient. This basic assumption is an approximation when streams of different shape of cross section are considered.

The exponent ⅔ for R in the Manning equation does not have a theoretical basis, and has been established as a rough empirical approximation from data on various kinds of open channel flow. Although the equation has been very useful, one should not lose sight of the fact that it has only a weak and incomplete theoretical justification and little empirical support as far as its application to sewers is concerned.

In this study, an equation was sought which would represent such experimental data as are available and would simplify calculations of relative velocities and quantities of flow. Only pipes of circular cross section are considered.

General Equation Relating V and Q

It has been found that the relationship between V and Q in sewers of circular cross section can be well represented by the general formula:

$$\frac{V}{V_F} = m\left(\frac{Q}{Q_F}\right)^w \qquad (1)$$

A synopsis of extensive data on flow in partly filled sewers was made by Camp [1], who described the results graphically. Selection of constants for Equation 1 for best fit to Camp's curves gives:

$$\frac{V}{V_F} = 1.053\left(\frac{Q}{Q_F}\right)^{0.29} \qquad (2)$$

To show the closeness of fit, Table 1 was prepared in which velocity ratio was calculated for various depths of flow. It was necessary to prepare a carefully interpolated series of values from Camp's curves to even demonstrate the trend of deviations. Over a range of flow ratio from 1 to 100 per cent, at 90 per cent depth ratio, the differences between the calculated and empirical results are less than 2 per cent. From 90 to 100 per cent depth ratio, there is an unstable region in which the calculated Q is greater than that for a full pipe. Under ideal conditions, this 100 per cent plus flow can be attained, but it probably rarely happens in a sewer in use except on a backwater curve. Equation 2 actually gives a good approximation of flow well into this range but misses the point of full flow by 5.3 per cent; i.e., by m-1.

Straub and Morris [2] conducted very careful tests under laboratory conditions in concrete pipes of 18, 24, and 36 in. diameter at a slope of 0.002. Experiments on partial flow were made only with the 18 and 24 in. pipes. When flowing full the 18 and 24 in. pipes yielded a Manning n value of 0.0100 when the hydraulic gradient was 0.002, as determined by interpolation from data in the reference cited. Fig. 1 shows the n values found at various depth ratios when the pipes were flowing partly filled.

These data also can be well represented by Equation 1, and the same value of 0.29 for the exponent w is satisfactory, but m is different. The dotted line on Fig. 1 shows apparent n values for the Manning equation assuming that velocity conforms to the equation:

$$\frac{V}{V_F} = 1.147\left(\frac{Q}{Q_F}\right)^{0.29} \qquad (3)$$

Table 1

Comparison of Equation 2 with Camp's Data

Depth Ratio d/D	Flow Ratio Q/Q_F	Velocity ratio: Empirical Camp's curves	Velocity ratio: Calculated, Equation 2
0.05	0.004	0.218	0.210
0.10	0.017	0.326	0.322
0.15	0.038	0.410	0.410
0.20	0.069	0.482	0.485
0.30	0.153	0.604	0.613
0.40	0.265	0.711	0.719
0.50	0.403	0.805	0.810
0.60	0.556	0.887	0.884
0.70	0.716	0.957	0.955
0.80	0.868	1.010	1.010
0.90	0.998	1.052	1.052

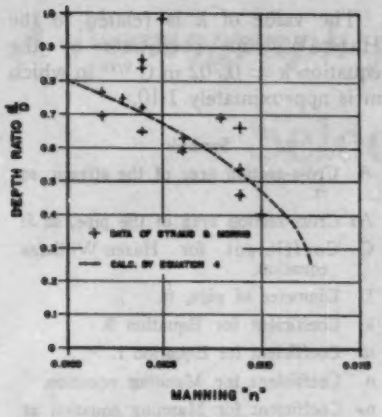

Fig. 1. COMPARISON of data of Straub and Morris with calculations from Equation 4.

The apparent n values are obtained by combining Equations 3 with the Manning equation, giving:

$$\frac{n}{n_F} = (1.147)^{-1.41}\left(\frac{R}{R_F}\right)^{2/3}\left(\frac{A}{A_F}\right)^{-0.41} \quad (4)$$

Except for the point representing a full pipe and three points in or close to the unstable flow range, which is upward from 0.85 depth, the dotted line is a good fit for the data. It shows that Equation 3 represents the data much better than does the Manning equation in which n is a constant.

If it were assumed that the Manning equation did represent velocity in the partly filled pipe, an equation of the form of Equation 1 would still be a fair alternative with m = 1.20 and w = 0.29. The Manning equation would predict a relative velocity about 7 per cent lower than this equation at a depth ratio of 0.80, approx. 100 per cent of capacity; 5 per cent higher at a depth ratio of 0.20, and 3.6 per cent lower at a depth ratio of 0.02. Since the purpose of this study is to deduce an equation which represents observed flow, the value of 1.20 for the constant m required to make Equation 1 approximate the Manning equation, is not given weight in the subsequent considerations.

From the experimental data, it appears that the m value for Equation 1 may be between 1.05 and 1.15. It is expected there will eventually be more experimental data to serve as a basis for choosing the value of m. The utility of the equation is not materially reduced by the present uncertainty about the m value. This only serves to relate the velocity at partial flow to velocity at full flow, which is a matter of subsidiary concern.

Developments from the Basic Equation

For the present, the basic equation will be written:

$$\frac{V}{V_F} = m\left(\frac{Q}{Q_F}\right)^{0.50}$$

Cross section area of a stream is related to other quantities as follows:

$$\frac{A}{A_F} = \frac{Q}{Q_F} \div \frac{V}{V_F}$$

$$\frac{A}{A_F} = \frac{Q}{Q_F} \div m\left(\frac{Q}{Q_F}\right)^{0.50} = \frac{1}{m}\left(\frac{Q}{Q_F}\right)^{0.50} \quad (5)$$

$$\frac{Q}{Q_F} = \left(m \times \frac{A}{A_F}\right)^{1.41} \quad (6)$$

$$\frac{V}{V_F} = m^{1.41}\left(\frac{A}{A_F}\right)^{0.41} \quad (7)$$

Since the depth ratio, d/D, is geometrically related to A/A_F, the foregoing equations can be used in calculating the hydraulic elements at various relative depths of flow, provided a value is selected for m.

In order to calculate a specific rather than relative velocity, it is necessary to choose an equation for flow in the full pipe. The equation of Hazen and Williams is widely used for this. It is commonly written:

$$V = 1.318\ C\ R^{0.63}S^{0.54}$$

Studies by Scobey [3] on various kinds of pipes gave exponents for R of 0.58, 0.625, and 0.65, and exponents for S of 0.5, 0.53 and 0.555. From the report by Straub and Morris [2], it is calculated, on the basis of their Fig. 5, that the exponent of S is 0.56 for the 18 in. pipe and 0.54 for the 36 in. pipe. The exponent of R cannot be determined very precisely from the data, since there is only a two-fold range of R, but it appears to be about 0.60. The Hazen-Williams equation for full pipes seems to be well substantiated.

Derivation of a specific velocity equation for the partly filled pipe is as follows. From the Hazen-Williams equation:

$$V_F = 0.5503\ C\ D^{0.63}\ S^{0.54}$$
$$\text{and } Q_F = 0.4322\ C\ D^{2.63}S^{0.54}$$

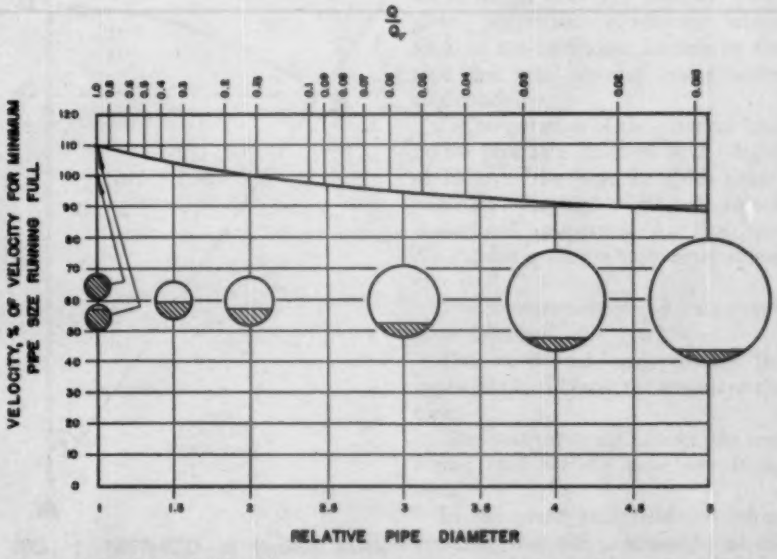

Fig. 2. COMPARATIVE velocities for same flow of sewage in pipes of various sizes.

Substituting these expressions in Equation 1, with $w = 0.29$:

$$\frac{V}{0.5503\ C\ D^{0.63}S^{0.54}} = m\left(\frac{Q}{0.4322\ C\ D^{2.63}S^{0.54}}\right)^{0.29}$$

$$V = 0.702\ m\ C^{0.71}\ Q^{0.29}\ S^{0.29}\ D^{-0.13}$$

Letting $k = 0.702\ m\ C^{0.71}$ (8)

$$V = k\ Q^{0.29}\ S^{0.29}\ D^{-0.13} \quad (9)$$

Use of this equation obviously must be confined to flows which are less than the capacity of the full pipe. If a Q is used which exceeds the capacity, a fictitious value of V is obtained.

The factor k is a function of the smoothness or roughness of the pipe. Values of this constant must be selected on the basis of experience with the kinds of sewers or other pipes under consideration. If the empirical basis for k is data from partly filled sewers, then the value of m is irrelevant as long as use of the equation is confined to these conditions.

It is interesting to note that velocity is not greatly affected by pipe size, decreasing only as the 0.13 power. Fig. 2 shows relative velocities in pipes of various relative sizes. In this calculation, m is assumed to be 1.10.

For the same S and Q, water in a full pipe flows at the same velocity as in a pipe of twice the diameter, flowing at 0.3 depth. There is however a range of greater velocities at intermediate sizes. Except for this comparison with a full pipe, enlargement of a pipe sufficiently to double the capacity decreases the velocity 3½ per cent.

The conclusion that diameter has a relatively small effect is not dependent upon the equations here deduced. If a similar figure is prepared on the assumption that the Manning equation is valid, there is a maximum of velocity in the vicinity of a diameter about one and a half times the minimum diameter, but the total range of change is about the same.

It is interesting to note that velocity, for any given Q, is not proportional to reciprocal n, but to its 0.71 power. This is because a change of n is balanced by a change of both V and A. Similarly, V, for any given Q, does not vary as the square root of S, but as the 0.38 power of S.

A subsequent paper will present results of a survey of k values of sewers in use.

Summary

The following equation has been deduced for calculating velocity of flow in a partly filled pipe of circular cross section.

$$V = k\ Q^{0.29}\ S^{0.29}\ D^{-0.13}$$

This equation conforms to available data better than the Manning equation.

The value of k is related to the Hazen-Williams coefficient by the equation $k = 0.702\ m\ C^{0.71}$ in which m is approximately 1.10.

Symbols

- A Cross-section area of the stream, sq ft
- A_F Cross-section area of the pipe, sq ft
- C Coefficient for Hazen-Williams equation.
- D Diameter of pipe, ft.
- k Coefficient for Equation 9.
- m Coefficient for Equation 1.
- n Coefficient for Manning equation.
- n_F Coefficient for Manning equation at full flow.
- Q Flow, cfs
- Q_F Flow of full pipe, cfs
- R Hydraulic radius, ft.
- R_F Hydraulic radius of full pipe, or D/4, ft.
- S Slope ratio.
- V Velocity, fps.
- V_F Velocity at full flow, fps.
- w Exponent for Equation 1.

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A Nomograph for the

Selection of Pipe Classes

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EDITOR'S NOTE: The nomograph developed here was drawn up to facilitate determination of pipe classes for conduits subjected to simultaneous internal pressure and external load.

■ A NOMOGRAPH has been drawn up in order to facilitate the determination of pipe classes for conduits subjected to simultaneous internal pressure and external load. The nomograph (Fig. 4) is based on determination of loads by Marston's[1] and Spangler's[2] theories and on the relationship between internal pressures and external loads already established for various types of pipe.

The combination of pressures and loads both within and without the pipe is further complicated by numerous factors affecting the external load and the equivalent three-edge bearing load.

In the nomograph there are two correlated parts. The right-hand side gives the load on a pipe in trench or projection condition. The left-hand curves show the relation between internal pressure and external load. Each part may stand by itself. Each part is discussed in turn and then both are considered together as a whole.

Determination of Load on Pipe

The load on pipe is affected by the following factors:

1. H, depth of fill over crown.
2. Breadth (depends on field conditions)
   (a) B_d, width of trench at crown (trench condition).
   (b) B_c, pipe outer diameter (projection condition).
3. Soil properties.
   (a) δ, unit weight of fill material.
   (b) K, ratio of active lateral pressure to the vertical as used in Rankine's formula.
   (c) μ, coefficient of internal friction of fill material.
   (d) μ^1, coefficient fill material and tion between fill material and sides of trench.

According to Marston[1] the earth fill load per linear unit of pipe is:

(a) For trench condition

$$W_d = C_d \, \delta \, B_d^2 \qquad (1a)$$

where

$$C_d = \frac{1 - e^{-2k\mu^1 \frac{H}{B_d}}}{2K\,\mu'} \qquad (2)$$

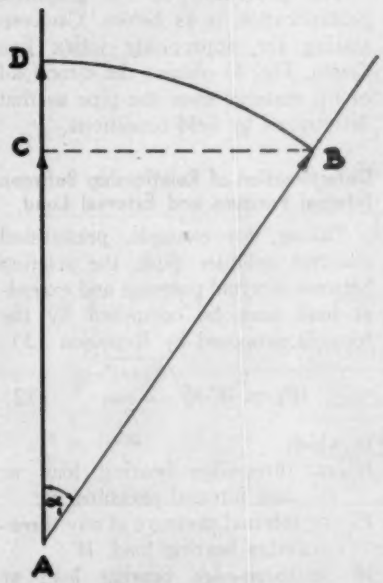

FIG. 1. METHOD of finding earth load on pipe due to change in unit weight of fill.

(b) For projection condition

$$W_c = C_c \, \delta B_c^2 \qquad (3a)$$

where

$$C_c = \frac{e^{2K\mu \frac{H}{B_c} - 1}}{2K\,\mu} \qquad (4)$$

That is,

$$W_d = \delta \, f\,(K\mu', H, B_d) \qquad (1b)$$

$$W_c = \delta \, f\,(K\mu, H, B_c) \qquad (3b)$$

In order to draw the load curves of earth fill on pipe as a function of height of fill above the pipe crown, it is necessary to determine definite values for $K\mu'$, B_d, and δ in the case of trench condition, and for $K\mu$, B_c and δ in the case of projection condition.

A nomograph is prepared which is based on:

1. Computation of the external load on the pipe as a function of the depth of fill over the pipe for complete projection condition, which leads to the maximum loading on the pipe that may possibly occur under any condition.

2. Computation of the external load on the pipe as a function of the depth of fill over the pipe for ditch condition for varying width of trench under soil properties, δ_o, $K_c\mu$, and $K_o\mu^1_o$, for a pipe whose outer diameter is B_c.

The construction of the nomograph is as follows:

The horizontal scale shows the depth of the fill over the crown of the pipe.

The vertical scale shows the external load on the pipe per linear unit.

In the event that field conditions establish that the unit weight of the fill material, δ_1, differs from δ_o, for which the nomograph is constructed,

and $K_1\mu'_1 = K_o\mu'_o$, then the load W_{do} obtained from the nomograph must be multiplied by the ratio $\frac{\delta_1}{\delta_o}$ (the load is a linear function of δ).

$$W_{do} = C_{do}\, B_d^2\, \delta_o \qquad (5a)$$

$$W_{d1} = C_{do}\, B_d^2\, \delta_1 = [C_{do}\, B_d^2\, \delta_o]\, \frac{\delta_1}{\delta_o} = W_{do}\, \frac{\delta_1}{\delta_o} \qquad (6a)$$

(C_d is independent of δ).

If the value for δ_o is chosen so that $\delta_o < \delta_1$, then

$$\frac{\delta_1}{\delta_o} = \frac{1}{\cos\alpha_1} = v_1 \qquad (7)$$

and

$$W_{d1} = W_{do}\, v_1 \qquad (6b)$$

This multiplication can be done by the following method (Fig. 1):

If vector $\overline{AC}$ represents load W_{do}, vector $\overline{AB}$ lying on the index line that makes angle α_1 with $\overline{AC}$ equals $\overline{AC}/\cos\alpha_1$. From A as a center, draw arc BD. Then $\overline{AD}$ represents the required load W_{d1}, inasmuch as $\overline{AD} = \overline{AB} = \overline{AC}/\cos\alpha_1$.

Hence, if a system of arcs be drawn, the center of which is the origin of index lines inclined at various angles, the graphical multiplication for various conditions may be performed (Fig. 2).

The problem is further complicated in the event that field conditions establish that the unit weight of the fill material, δ_1, and the coefficient $K_1\ \mu'_1$ differ from δ_o and from $K_o\ \mu'_o$, for which the nomograph is constructed. (The factor $K\mu'$ does not vary linearly.)

$$W_{do} = C_{do}\, B_d^2\, \delta_o \qquad (5a)$$

$$W_{d1} = C_{d1}\, B_d^2\, \delta_1 \qquad (5b)$$

but

$$W_{d1} = W_{do}\, \frac{\delta_1}{\delta_o}\, \frac{C_{d1}}{C_{do}} \qquad (8)$$

and

$$\frac{C_{d1}}{C_{do}} = \frac{2K_o\mu'}{2K_1\mu'_1}\, \frac{1-e^{-2K_1\mu'_1\frac{H}{Bd}}}{1-e^{-2K_o\mu_o\frac{H}{B_d}}} = \eta \qquad (9)$$

Let η be drawn as a function of $\frac{H}{B_d}$ for various values of $K\mu'$ (Fig. 3). The appropriate value of η may be found from this auxiliary nomograph. Then

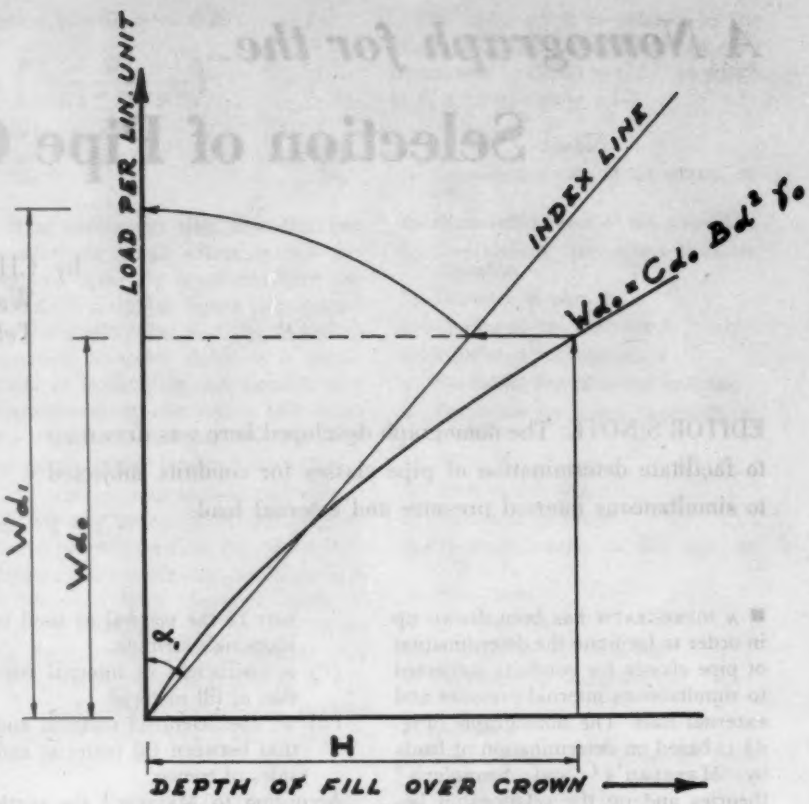

FIG. 2. GRAPICAL multiplication for varied conditions.

$$\frac{\delta_1}{\delta_o}\, \frac{C_{d1}}{C_{do}} = \frac{1}{\cos\alpha_2} = v_2 \qquad (10)$$

$$W_{d1} = W_{do}\, v_2 \qquad (11)$$

The procedure of the graphical multiplication is as before. On consulting the appropriate index line (right, Fig. 4) obtains the same load of fill material over the pipe as that determined by field conditions.

Determination of Relationship Between Internal Pressure and External Load

Taking, for example, prestressed concrete cylinder pipe, the relation between internal pressure and external load may be computed by the formula proposed by Kennison (3):

$$W_1 = W \sqrt[3]{\frac{P_o - P_1}{P_o}} \qquad (12)$$

in which

W_1 = three-edge bearing load at any internal pressure, P;
P_1 = internal pressure at any three-edge bearing load, W;
W = three-edge bearing load at $P_1 = O$; and
P_o = internal pressure at $w_1 = O$.

Construction of the nomograph (left, Fig. 4) will be as follows:

The horizontal scale shows the pressure within the pipe.

The vertical scale shows the external load on the pipe per linear unit.

Inasmuch as pipes of equal diameter are designed to different working pressures, the result is a number of curves of similar shape.

As previously stated, the supporting strength of pipe is affected by both its specific strength and its bedding conditions.

The internal pressure—external load curves for a number of pipes, equal in diameter but differing as to working pressures and specific strength, may be constructed for a bedding condition coefficient β_o. The relation between the internal pressure and the external load is

$$W_1 = \beta_o\, W \sqrt[3]{\frac{P_o - P_1}{P_o}} \qquad (13)$$

In case the supporting strength must be determined for another bedding factor β_1, the load obtained from the nomograph must be multiplied

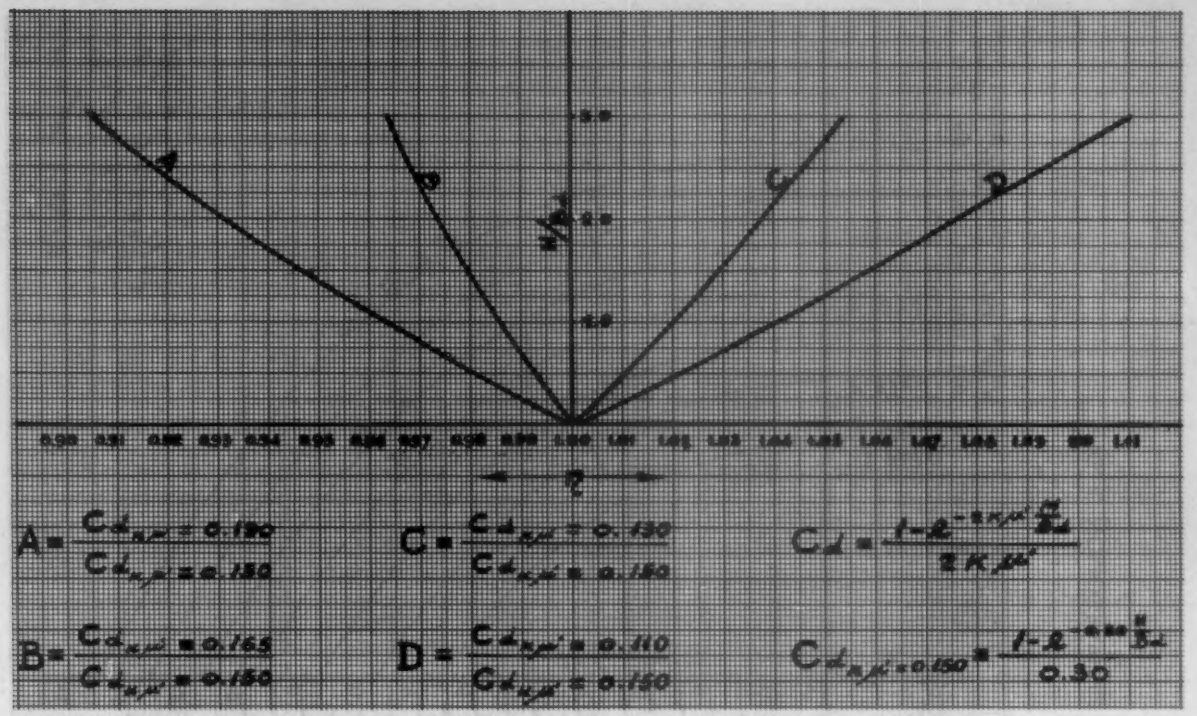
A
B
C
D
2.0
1.0
0.0
η
A = C_d (H/B_d = 0.190) / C_d (H/B_d = 0.150)
B = C_d (H/B_d = 0.165) / C_d (H/B_d = 0.150)
C = C_d (H/B_d = 0.130) / C_d (H/B_d = 0.150)
D = C_d (H/B_d = 0.110) / C_d (H/B_d = 0.150)
C_d = (1 − e^(−2 K μ′ H/B_d)) / (2 K μ′)
C_d (H/B_d = 0.150) = (1 − e^(−0.30 H/B_d)) / 0.30

FIG. 3. NOMOGRAPH for determining values of η as a function of H/B_d.

Table 1
Typical Solutions of Various Cases

Case No.	Installation Condition	Soil Wt. (pcf)	$K\mu'$ or $K\mu$	B_d or B_c (ft)	H (ft)	P (psi)	Bending Factor	Pipe Class	Solutions
									$p = 0.02 \frac{\eta \gamma}{\beta}$ $\qquad \beta = \frac{\eta \gamma}{p}$
1	Complete projection	100	0.15	7.0	5.5	70	1.1	2	$p = \frac{0.02 \times 100}{1.1} = 1.82$ $\qquad \therefore$ Pipe class = 2
2	Ditch	112	0.11	9.0	10.0	80	?	4	$p = 1.49$ (from nomograph) $H/B_d = \frac{10.0}{9.0} = 1.11$ $\qquad \therefore \eta = 1.045$ $\therefore \beta = 0.02 \times 1.045 \times \frac{112}{1.49} = 1.57$
3	Ditch	120	0.165	11.0	13.0	?	1.9	7	$H/B_d = \frac{13.0}{11.0} = 1.18$ $\qquad \therefore \eta = 0.984$ $p = \frac{0.984 \times 0.02}{1.9} \times 120 = 1.24$ $\therefore P = 93$ psi
4	Ditch	130	0.11	12.0	?	120	1.5	5	$p = \frac{0.02 \times 130}{1.5} = 1.73$ Complete projection condition prevails $\therefore H = 6.4$ ft
5	(Find load on the pipe for Case 3)								$p = 1.24 \times \frac{1.9}{1.5}$ $\therefore W = 11{,}250 \times \frac{1.9}{1.5} = 14{,}250$ lb

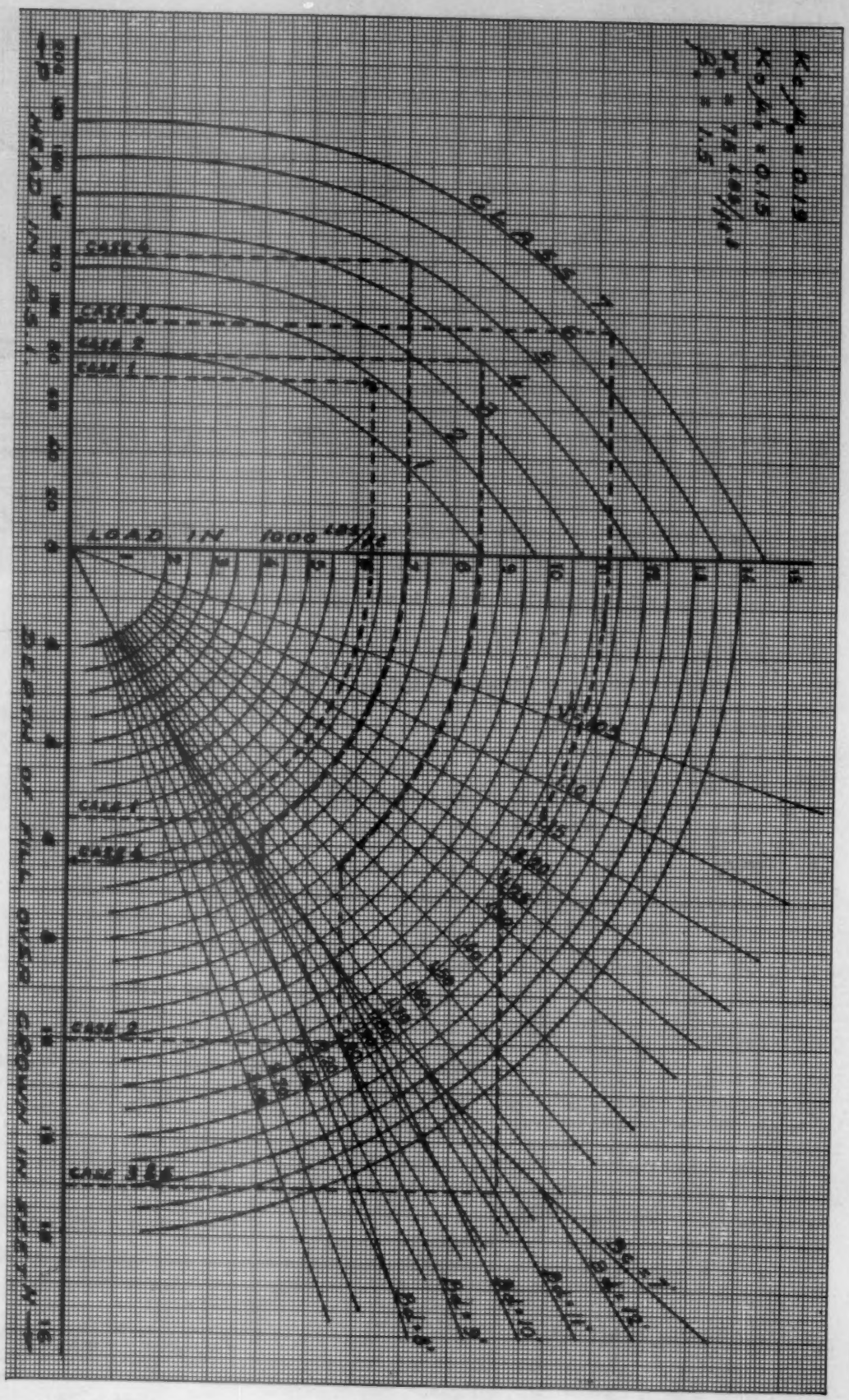

FIG. 4. NOMOGRAPH for a pipe subjected to external load and internal pressure.

by the ratio $\frac{\beta_1}{\beta_o}$. (The load is a linear function of β.)

$$W_1' = W \sqrt[3]{\frac{P_o - P_1}{P_o}} = W_1^o \frac{\beta_1}{\beta_o} \quad (14)$$

$$\frac{\beta_1}{\beta_o} = \frac{1}{\cos \alpha_3} = v_3 \quad (15)$$

Determination of Pipe Class for Conduits Subjected to Simultaneous Internal Pressure and External Load

All that remains is to combine the external load nomograph with the external load—internal pressure nomograph, both of which have a common vertical scale and load axis (Fig. 4).

Let the nomograph be constructed for pipes of outer diameter B_o and for varying widths of trench increasing by steps for δ_0, $K_o\,\mu$, $K_o\mu'_o$ and for bedding factor β_o, and suppose it is required to determine the pipe class which is subjected to other conditions, say δ_1, $K_1\,\mu'_1$, and β_1*. It is necessary to establish the value of

$$\frac{\delta_1 C_{d1} \beta_o}{\delta_o C_{do} \beta_1} = \eta \frac{\delta_1 \beta_o}{\delta_o \beta_1} = v_n \quad (16)$$

in order to find the appropriate index line and then to perform the graphical multiplication.

In order to clarify the operation of determining pipe class for conduits subjected to simultaneous internal pressure and external load, the following example is used with nomenclature as previously stated:

B_o = 7.0 ft, δ_o = 75.0 pcf, $K_o\mu'_o$ = 0.15, $K_o\mu_o$ = 0.19, β_o = 1.5, and B_d = varying width of trench commencing at 8.0 ft and increasing by stages of 1 ft.

Pipe Class	P_o (psi)	W_o (lb/ft)
1	80	5,740
2	100	6,470
3	115	7,140
4	130	7,860
5	145	8,470
6	160	9,070
7	175	9,660

When either H or B_d is unknown and $K_o\mu'_o \neq 0.15$, H/B_d cannot be found immediately, and the solution is arrived at by the method of approximation:

1. Case $K_o\mu'_o = 0.15$ must be solved and thereby the unknown found.
2. Find H/B_d.
3. Find unknown η.
4. Find v_n.*
5. Find the unknown through use of the nomograph (Fig. 4).

The use of the nomograph can be made clear through solution of a number of cases as presented in Table 1.

One of the advantages of the new nomograph is that it can readily show whether pipe load depends on trench width or projection condition.

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* $\frac{\delta_1 C_{d1}}{\delta_o C_{do}} W_{do} = \frac{\beta_1}{\beta_o} W_1^o$

$W_1^o = \frac{\delta_1 C_{d1}}{\delta_o C_{do}} \frac{\beta_o}{\beta_1} W_{do}$

* $v_n = \frac{\delta_1 \beta_o}{\delta_o \beta_1} \eta = \frac{1.5}{75} \frac{\delta \eta}{\beta_1} \eta = 0.002 \frac{\delta \eta}{\beta_1}$

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Design of Large Flows
in Open Channels

by J. TARRANT
Ruislip, England

■ SINCE 1944 the writer has designed many Parshall flumes for the measurement of water flow and of sludge wastes, and these have been successfully operated in conjunction with indicators, recorders, and integrators on water treatment plants installed in many parts of the world.

The advantages of this type of flume, as compared with weirs, in reduced head loss, freedom from silting, and, in some installations, reduced pumping costs, have been amply demonstrated. Also, the accuracy of measurement with carefully constructed flumes has been shown, by volumetric comparison with flow indicators, to be within the usually accepted limits applied to weir flow.

In some of the installations referred to, it was necessary to provide flumes larger than those covered by the information in the earlier article.* Therefore, data for the design of flumes larger than 96 in. throat width are now presented. This information is based on *Bulletin* 386, "Parshall Flumes of Large Size," by R. L. Parshall, published by the Bureau of Agricultural Engineering, U. S. Department of Agriculture, on work at the Colorado Experiment Station, Fort Collins, Colorado. The formula given applies to flumes having throat widths from 8 ft. to 50 ft. The sizes given in Table 1, taken from *Bulletin* 286, could probably be suitable for a choice to be made. If, however, because of site or construction conditions, a size not given in the Table 1 is required, the dimensions indicated in Fig. 1 may be determined as shown by the following example:

For a flume 35 ft. wide, dimensions *A, B, C,* etc., might be as for a 30 ft. wide flume; whereas, for a 38 ft. wide flume, these dimensions could be as for one 40 ft. wide; but always the dimension J is to be $\frac{2}{3}\left(\frac{W}{2}+4\right)$ measured back from the crest, or sill, along the side wall.

The formula for large flumes is $Q = (3.6875W + 2.5)\ H_A^{1.6}$ Q is the discharge, in cubic feet per second; W is the width of throat, in feet; and H_A is the head on the crest, or sill, in feet.

As in the previous article, the formula applies to "free flow" conditions; that is, the downstream head must not be allowed to reach a level at which the single head reading would become inaccurate. For these large flumes, the limiting submerged flow is 80 per cent, which means that the level downstream of the flume must be such that the loss of head through the flume (the difference between the upstream and downstream water levels) must be not less than 20 per cent of the measured head H_A. It is

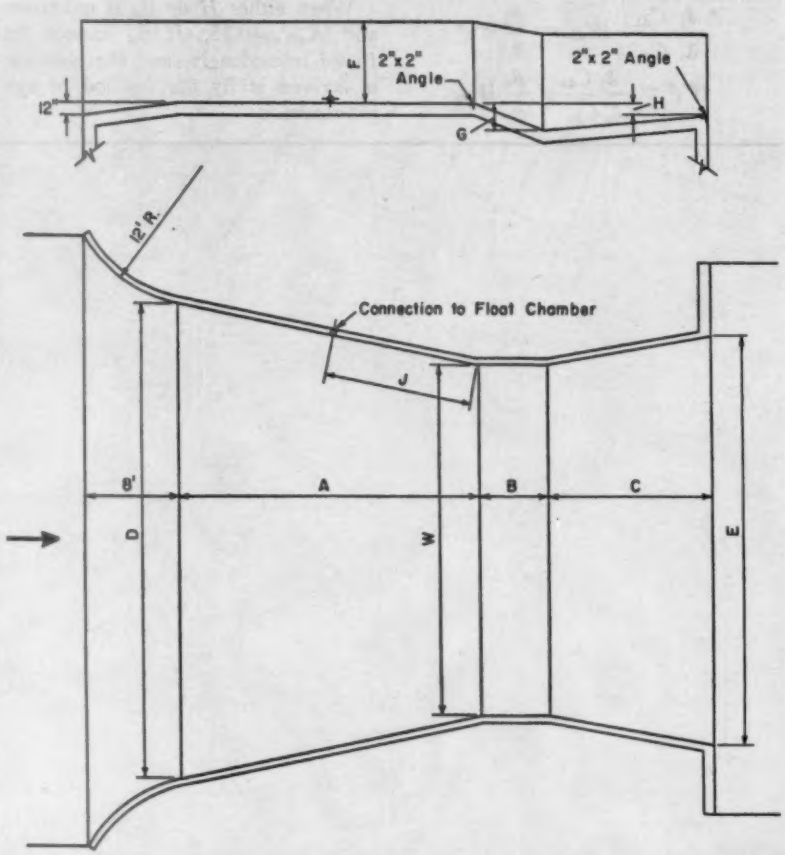


FIG. 1. PROPORTIONS of wide Parshall flumes for flow measurements in open channels.

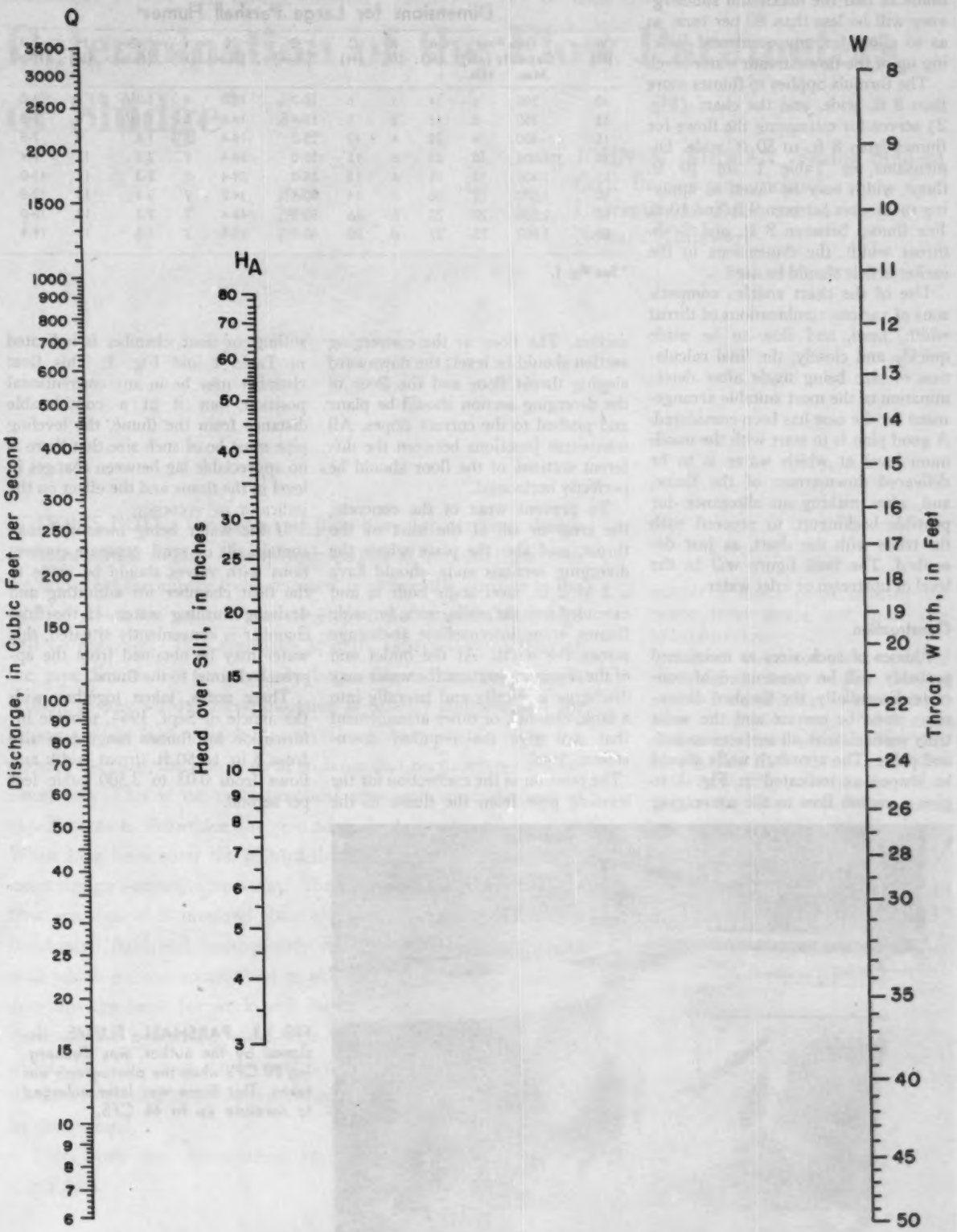


FIG. 2. NOMOGRAPH for determining "free flow" discharge by Parshall flumes of large size.

advisable to arrange the siting of the flume so that the maximum submergence will be less than 80 per cent, so as to allow for any accidental backing up of the downstream water level.

The formula applies to flumes more than 8 ft. wide, and the chart (Fig. 2) serves for estimating the flows for flumes from 8 ft. to 50 ft. wide. Dimensions in Table 1 for 10 ft. flume width may be taken as applying to all sizes between 9 ft. and 10 ft. For flumes between 8 ft. and 9 ft. throat width, the dimensions in the earlier article should be used.

Use of the chart enables comparisons of various combinations of throat width, head, and flow to be made quickly and closely, the final calculation of size being made after determination of the most suitable arrangement for the case has been considered. A good plan is to start with the maximum level at which water is to be delivered downstream of the flume, and, after making an allowance for possible backingup, to proceed with the trials with the chart, as just described. The final figure will be the level of upstream or inlet water.

Table 1
Dimensions for Large Parshall Flumes[a]

W (ft)	Free Flow Capacity (cfs) Max.	Min.	A (ft)	B (ft)	C (ft)	D (ft-in)	E (ft-in)	F (ft)	G (ft-in)	H (in)	J (ft-in)
10	200	6	14	3	6	15-7¼	12-0	4	1-1½	6	6-0
12	350	8	16	3	8	18-4¾	14-8	5	1-1½	6	6-8
15	600	8	25	4	10	25-0	18-4	6	1-6	9	7-8
20	1,000	10	25	6	12	30-0	24-4	7	2-3	12	9-4
25	1,200	15	25	6	13	35-0	29-4	7	2-3	12	11-0
30	1,500	15	26	6	14	40-4¾	34-8	7	2-3	12	12-8
40	2,000	20	27	6	16	50-9½	45-4	7	2-3	12	16-0
50	3,000	25	27	6	20	60-9½	56-8	7	2-3	12	19-4

[a] See Fig. 1.

Construction

Flumes of such sizes as mentioned probably will be constructed of concrete. Essentially, the finished dimensions must be correct and the walls truly vertical, with all surfaces smooth and plane. The approach walls should be shaped as indicated in Fig. 1 to give a smooth flow to the converging section. The floor of the converging section should be level; the downward sloping throat floor and the floor of the diverging section should be plane and pitched to the correct slopes. All transverse junctions between the different sections of the floor should be perfectly horizontal.

To prevent wear of the concrete, the crest or sill at the inlet of the throat, and also the place where the diverging sections ends, should have a 2 by 2 in. steel angle built in and extended into the walls, with, for wide flumes, some intermediate anchorage across the width. At the outlet end of the diverging section the water may discharge vertically and laterally into a tank, channel, or other arrangement that will give the required downstream level.

The position of the connection for the leveling pipe from the flume to the stilling, or float, chamber is indicated in Table 1 and Fig. 1. This float chamber may be in any conventional position, but if at a considerable distance from the flume, the leveling pipe must be of such size that there is no appreciable lag between changes in level in the flume and the effect on the indicator or recorder.

If the water being measured may contain silt or sand, separate connections with valves should be made to the float chamber for admitting and draining flushing water. If the float chamber is conveniently situated, this water may be obtained from the approach channel to the flume.

These notes, taken together with the article of Sept. 1944, provide information for flumes ranging in size from 3 in. to 50 ft. throat width and flows from 0.03 to 3,500 cubic feet per second.

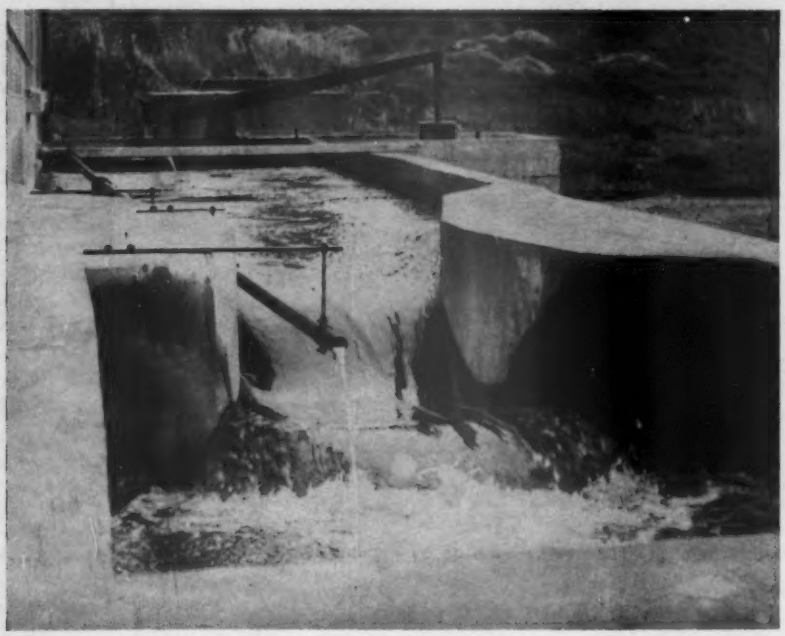


FIG. 3. PARSHALL FLUME, designed by the author, was discharging 20 CFS when the photograph was taken. This flume was later enlarged to measure up to 46 CFS.

A research report tells how a capillary viscometer can be used for . . .

Determination of the Flow Parameters of Sludge*

by JOHN M. SIRMAN, Senior Student
Civil Engineering School
University of Delaware
Newark, Delaware

EDITOR'S NOTE: The design of pipe lines for carrying sludge is frequently a matter of applying empirical formulations with the hope that the sludge to be pumped is sufficiently similar to the one for which the relation was developed that a workable design will be obtained. This approach is quite satisfactory as long as the pipe line is not particularly long. Short lines are not too critical as any serious misapplication is usually compensated for by some other factor which is overestimated or, what is more frequently the case, the line is sized so large that no problems are encountered. This is the most practical approach since the cost of experiments to determine the size of a short line is not justified. When long lines enter the picture the situation shifts and a more exact design becomes important. The theoretical aspects of sludge flow are somewhat involved since sludge, unlike water, is a non-Newtonian fluid and consequently does not follow the formulae with which we are accustomed to work. In this paper the author develops the basis for work with fluids of this type and presents the basis for a formula which can be applied to sludge flow in pipes. In addition an experimental method is described by which the factors needed to apply this formula to a particular sludge can be determined.

This work was sponsored by a research grant from the U.S.P.H.S.

Introduction

■ MANY LIQUIDS THAT are transported in pipes today cannot be classified as Newtonian fluids. In other words, these liquids do not exhibit a direct proportionality between shear stress and shear rate in laminar flow.

One of these non-Newtonians of particular interest to the field of sanitary engineering is encountered when sludges are transported through pipe lines. Since circumstances may require that these distances be many miles in length, there is ample justification for use of the most rational procedures available for the design of pipelines.

This paper will demonstrate that such rational design techniques are based upon the fundamental hydraulic properties of these sludges, and will further show how these properties may be determined experimentally.

An understanding of non-Newtonian flow properties may best be reached by comparison with Newtonian behavior. The flow curves are expressed by Newton's equation:

$$T = \mu\left(\frac{du}{dy}\right)$$

where T = shear stress

$\left(\frac{du}{dy}\right)$ = shear rate

μ = viscosity of liquid.

Newtonian flow behavior is thus

*This paper was awarded first prize at the 22nd Annual Student A.S.C.E. Chapter Conference, sponsored by the Central Pa., Del., Lehigh Valley, and Philadelphia Sections A.S.C.E.

completely characterized by a single parameter, the viscosity.

In contrast, non-Newtonians are characterized by two flow parameters, as shown by the relationships in Table 1. Bingham plastics differ from Newtonian liquids only in the respect that an initial shear stress is necessary to produce flow. Pseudoplastics are characterized by a power function relationship. More generally, for any non-Newtonian liquid, whose properties are independent of time or duration of shear, the shear stress can be expressed simply as an unknown function of the shear rate.

Although sewage sludge has generally been classed as a Bingham plastic, there is still speculation as to its actual characteristics, and it is even quite possible that it may exhibit Bingham plastic behavior at higher concentrations and pseudoplastic behavior at lower concentrations.[1] Therefore, it would seem desirable to develop flow equations for the sludge based not on a particular non-Newtonian type but on the general relation that shear stress is merely a function of shear rate.

The flow parameters of fluids are determined with a capillary tube or a rotational viscometer, and these parameters are then used for design of pipelines in present day practice; either by a direct scale up from the flow curve, if laminar flow is present, or by obtaining a value of Fanning's friction factor, f, for a given apparent Reynold's Number. The flow parameters of the curve

TABLE I

SHEAR STRESS–SHEAR RATE RELATIONSHIPS

NEWTONIAN	$\tau = \mu\left(\frac{du}{dy}\right)$
BINGHAM PLASTIC	$\tau - \tau_y = h\left(\frac{du}{dy}\right)$
PSUEDO-PLASTIC	$\tau = K\left(\frac{du}{dy}\right)^n$
ANY TIME INDEPENDENT FLUID	$\tau = \mu_o\left(-\frac{dv}{dr}\right)$

can also be determined and used with the appropriate form of the Hagen-Poiseuille equation for design purposes.

Theory

To develop a general equation for any time-independent non-Newtonian fluid which does not depend on any particular shear stress—shear rate relation, it is necessary to begin with the general expression for the laminar flow of a fluid in a circular pipe or tube,

$$T = \mu o\left(\frac{dv}{dr}\right).$$

The variables may be separated and the equation simplified if the ratio of shear stress to radius at any point is considered as equal to the ratio of these variables at the wall. The result gives the value for the point velocity,

$$Vi = \frac{\tau_w}{r_w}\int_{ri}^{r_w}\frac{r\,dr}{\mu_o},$$

where Vi = velocity at a given point
τ_w = shear stress at wall
rw = radius at wall
ri = radius at a given point
μ_o = apparent viscosity.

This cannot be integrated directly because μ_o is not known as a function of the radius. However, an expression for the flow rate, Q, in the pipe can be written as

$$Q = \int_0^{r_w} 2\pi ri\ Vi\ dri.$$

Substituting the above value for Vi and carrying out the integration on the right hand side,

$$Q = \frac{\pi\tau_w}{r_w}\int_0^{r_w}\frac{r^3\,dr}{\mu_o}.$$

By changing the independent variable from r to τ and letting

$$X = \frac{Q}{\pi r^3_w}, \quad \text{then}$$

$$X\tau^3_w = \int_0^{\tau_w}\frac{\tau^3\,d\tau}{\mu o}$$

which differentiates, by the use of Leibniz's rule to

$$\frac{dx}{d\tau_w}\tau^3_w + 3\tau^3_w X = \frac{\tau^3_w}{(\mu_o)_w} = -\left(\frac{dv}{dr}\right)\tau^3_w.$$

Since $X = \frac{Q}{\pi r^3_w} = \frac{2V}{D}$,

the final result becomes

$$\left(-\frac{dv}{dr}\right)_w = \frac{3}{4}\left(\frac{8V}{D}\right) + \frac{1}{4}\frac{d\left(\frac{V8}{D}\right)}{d(\tau_w)}.$$

This expression for the shear rate at the wall is known as the Rabinowitch-Mooney equation.

Metzner and Reed have modified

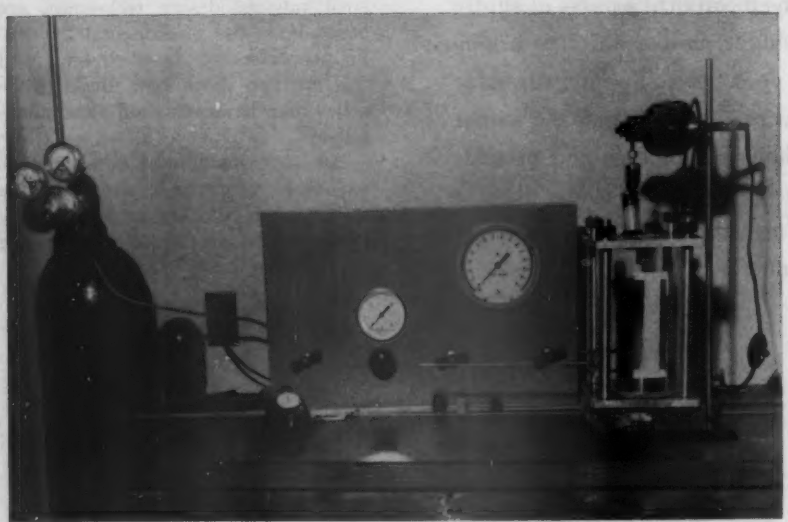


FIG. 1 EXPERIMENTAL EQUIPMENT

this equation by noting that, since

$$\frac{d\left(\frac{8V}{D}\right)}{\frac{8V}{D}} = d\left(\ln\frac{8V}{D}\right) \text{ and}$$

$$\frac{d(\tau_w)}{\tau_w} = d(\ln \tau_w),$$

the equation can be written as

$$\left(-\frac{dv}{dr}\right)_w = \frac{3}{4}\left(\frac{8V}{D}\right) + \frac{1}{4}\frac{8V}{D}\left[\frac{d\left(\ln\frac{8V}{D}\right)}{d(\ln \tau_w)}\right]$$

By letting

$$n' = \frac{d\left(\ln\frac{8V}{D}\right)}{d(\ln \tau_w)},$$

then

$$\left(-\frac{dv}{dr}\right)_w = \left(\frac{3n'+1}{4n'}\right)\frac{8V}{D},$$

the relationship between $\frac{8V}{D}$, which can be obtained directly from viscometric data, and the shear rate at the wall.

Integrating the expression for n′ gives

$$\tau_w = K'\left(\frac{8V}{D}\right)^{n'},$$

which holds for any time-independent non-Newtonian. K′ can be considered an index of the consistency of the fluid, and n′ a characteristic of the extent of non-Newtonian behavior. When n′ equals one, the expression reverts to that for a Newtonian fluid, and K′ is the viscosity of the fluid.

A generalized Reynold's Number for all time-independent fluids can now be obtained by combining

$$\tau_w = K'\left(\frac{8V}{D}\right)^{n'},$$

where

$$\tau_w = \frac{D\Delta P}{4L}$$

which can be shown by making a force balance on a segment of flow in pipe; the Fanning friction factor,

$$f = \frac{D\Delta P}{4L} \Big/ \frac{\rho V^2}{2g},$$

where

- D inside diameter of pipe
- ΔP pressure drop along length, L, of pipe
- P density of liquid
- V mean velocity of flow in pipe
- g acceleration due to gravity;

and the standard Newtonian relationship between the Fanning friction factor and Reynold's Number in laminar flow,

$$f = 16/ N_{RE}.$$

The result is

$$N_{RE} = \frac{D^{n'}V^{2-n'}}{K'8^{n'-1}}P,$$

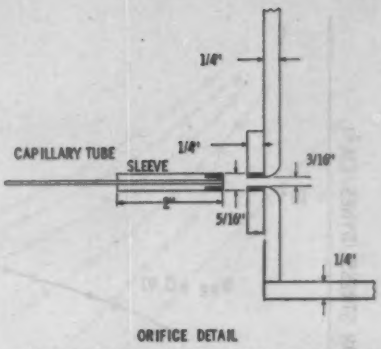
which can be used to predict the region of transition from laminar to turbulent flow, which usually occurs at $N_{RE} = 2100$.

Experimental Apparatus

A capillary tube viscometer consists essentially of a pressure cylinder, an accurate method of applying and measuring pressure, and a calibrated tube through which the sample is forced.

One of the first problems to consider when designing such a viscometer for use with sewage sludge is that of settling of the particles. Obviously, to prevent this the sample will have to be agitated in some manner while in the test cylinder. For the design used in this case, a stirring rod was built into the cylinder through a pressure-tight bushing that would take pressures well above the maximum used. This stirring rod was then driven during the test by a two-speed Fischer lab-motor. Actually it was necessary to use two different sized paddles on the rod, depending upon the solids concentration of the sample so that excessive agitation could be reduced, and yet still keep the sample completely mixed.

The test cylinder was made of a 10 in. length of lucite cylinder which was six inches nominal diameter with one-quarter inch walls.



ORIFICE DETAIL

FIG. 2. DETAILS OF THE ORIFICE

A bottom of one-quarter inch sheet lucite was glued on. The top was made of one-half inch aluminum plate seven and one-half inches square. The top of the cylinder was recessed into the top plate one-quarter inch and the seal was made with a neophrene rubber gasket. The top aluminum plate was held down by four vertical rods anchored into a similar plate at the bottom, as shown in Fig 1. The stirring rod and the pressure tap were inserted through the top.

An orifice (Fig. 2) was made in the side of the cylinder 1.5 in. up from the bottom of the cylinder. A three-sixteenths inch hole was cut completely through the cylinder and was counterbored on the inside of the cylinder to a reverse radius of approximately three-sixteenths inch, to reduce entrance losses due to a sudden contraction. A one-quarter inch lucite disc 2 in. in diameter was glued to the outside of the cylinder over the orifice and threaded with a five-sixteenths inch tap to accommodate the sleeve on the capillary tube.

The capillary tubes used were seamless, stainless steel tubes. Two nominal inside diameters were used, one-eighth inch, and one-sixteenth inch, and there were three different lengths for each diameter—one foot, three feet, and five feet. To mount the tubes in a horizontal position to the test cylinder, a two inch long, five-sixteenths inch diameter brass sleeve was welded onto the end of each tube and threaded, so that the tube could simply be screwed into place when used.

Pressurized nitrogen was chosen as a means of applying pressure to the cylinder. The gas pressure from the bottle was regulated in the line

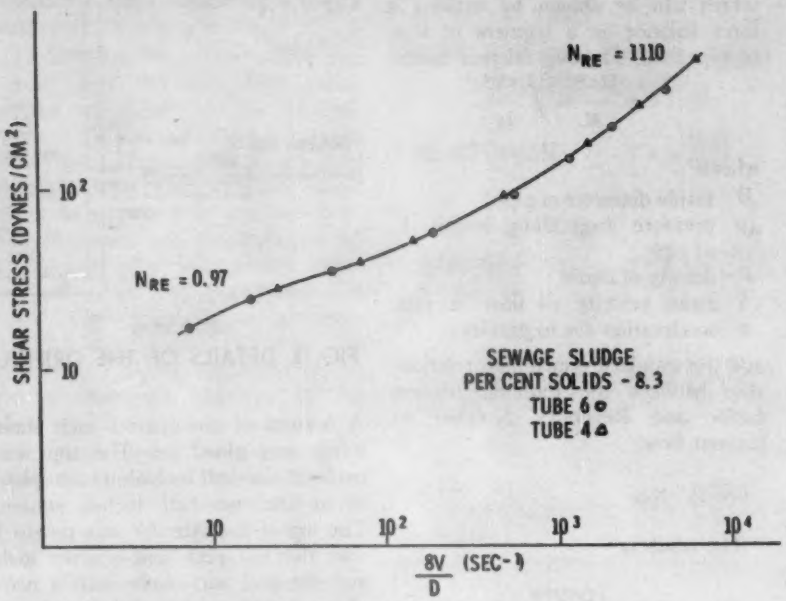


FIG. 3. EXPERIMENTAL RESULTS with 8.3 per cent sludge.

by a 0-15 psi regulator and the pressure indicated by a 6 in. laboratory test gage graduated and calibrated to 0.05 psi. The pressure line was attached to the test cylinder by means of a quick-couple assembly that simply snapped into place when a sample was ready to be run.

Experimental Procedure

The samples of sludge used were prepared from a single batch of digested sewage sludge from the sewage treatment plant at Wilmington, Delaware. The sludge was placed under vacuum for at least twenty-four hours to remove the majority of gases that might have been present. Nine samples were prepared by diluting the original material so that the solids concentration ranged from 2.8 per cent to 10.5 per cent by weight.

Because of occasional inert particles in the samples which were larger even than the inside diameter of the largest tube, it was necessary to strain the sludge. This was accomplished with a soil sieve with 0.20 centimeter openings. The percentage of solid material removed by the sieve was insignificant.

Having prepared the samples for testing, it was necessary to calibrate the capillary tubes to be used. The lengths could be satisfactorily measured with a scale. However, this method was practically impossible for determining the inside diameters of the tubes. Therefore, the tube diameters were calibrated with distilled water, which has a known viscosity and density at a specified temperature, by solving for D in the Hagen-Poiseulle equation for laminar flow of Newtonian liquids.

The temperature for all experiments was controlled by performing the tests in a constant temperature room, which remained at 20°C (± 1°C). Therefore, all equipment was maintained at 20°C and the samples were left in the constant temperature room long enough to be at that temperature before the test was run.

The data needed to determine the values of τ_w and $\frac{8V}{D}$ for a logarithmic plot of τ_w versus $\frac{8V}{D}$, is

D —diameter of tube, cm.,
L —length of tube, cm.,
P —density of sample, gm./cu. cm.,
ΔP —the pressure in dynes/sq. cm. at the tube inlet minus that at the outlet (actually the pressure applied to the cylinder),
Z_1 and Z_2 —the static head at beginning and end of the run, respectively, cm.,
T —time of flow in tube, sec.,
W —weight of sample that flows through the tube, cm. A force balance on a segment of fluid within the pipe shows that

$$\tau_w = \frac{D\Delta P}{4L}.$$

Therefore, the shear stress for various rates of flow is easily obtained from the viscometric data. The corresponding value of $\frac{8V}{D}$ is also obtained by using the data, observing that

$$\frac{8V}{D} = \frac{8Q}{DA} = \frac{32W}{P\pi D^2 T}.$$

Usually nine or ten points, corresponding to pressures from 0.20 psi to the maximum 15 psi, plotted on logarithmic coordinates are enough to adequately describe the flow curve for a given sample.

Design Procedure

Having obtained the flow curve for a sample, the design of pipes to carry a sludge with the same solids concentration and at the same temperature can be made by a scale-up from the curve plotted on logarithmic coordinates as shown in Fig 3.[2] For such a scale-up, it is well to have a curve determined from data from two different length tubes. This reduces the influence of possible time dependency of the sludge and inevitable errors in obtaining data. The data for a five foot tube and a three foot tube agree very well, as can be seen in Fig 3.

However, since it is usually necessary to determine the apparent Reynold's Number for given points on a curve in order to locate the region of transition from laminar to turbulent flow, pipeline design is also practical using the relationships between Reynold's Number and Fanning's friction factor shown in the theoretical discussion for laminar flow.[3] In the turbulent range, emperical relationships between N_{RE} and f for non-Newtonians are available.

Reynold's Number is a function the flow parameters k' and n'; therefore it is necessary to determine these parameters to compute N_{RE} Referring to Fig 4, it is obvious that n' is the slope of the curve

at given values of $\frac{D\Delta P}{4L}$ $\frac{8V}{D}$, and k′ equals the intersection of the ordinate by the tangent n′ at a value of $\frac{8V}{D} = 1$.

It was also shown in the theoretical section that the shear rate at the wall is given by

$$\left(-\frac{dv}{dr}\right)_w = \left(\frac{3n'+1}{4n'}\right)\frac{8V}{D}$$

Therefore, having determined the flow parameter n′, $\frac{8V}{D}$ can be converted to the shear rate at the wall. This gives paired values of shear stress and shear rate.

Results

The results depicted in Fig 5 clearly illustrate that solids concentration is a very important parameter of sludge flow. The degree of departure from Newtonian flow, with a slope of unity, increases with increasing concentrations and decreasing flow rates for concentrations of 5.2 per cent through 10.5 per cent. However, the 2.8 per cent concentration has a slope of unity in laminar flow, which indicates Newtonian properties. Its displacement from the curve for water is the result of its having a larger viscosity than water. These results confirm the experience of previous investigators in that sludges whose solids concentrations are low behave similarly to water.

Rational design of pipelines to carry sludges is possible when the range of concentration is known, and basic experimental data are available to determine flow parameters. The equipment which has been described in this report is considered satisfactory for the collection of such data.

Summary

A capillary viscometer has been utilized to obtain viscometric data for sewage sludge, whose solids concentration ranges from 2.8 to 10.5 per cent. The tubes used with the viscometer were smooth, stainless steel ones of two diameters, nominally one-eighth inch and one-sixteenth inch. No attempt was made to investigate pipe roughness.

The flow curves obtained from the data were plotted as shear stress versus $\frac{8V}{D}$, and clearly indicated that increase of solids concentration increased the degree of non-Newtonian behavior.

Methods were presented by which the design of larger smooth pipes can be made from the flow curves developed from the viscometric data.

It seems reasonable to conclude that this method of determining a flow curve with a capillary viscometer to be used for pipeline design is a valid method, and could be applied in preference to the more empirical methods now in use.

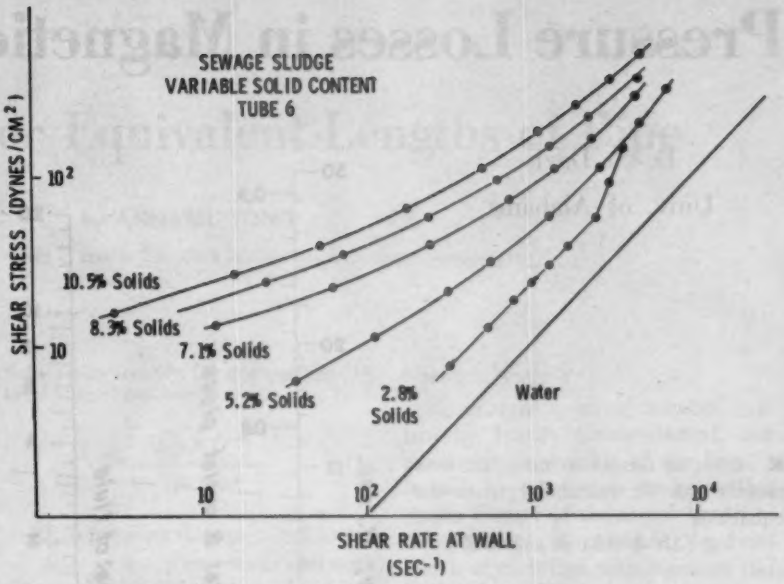


FIG. 4. EXPERIMENTAL RESULTS with variable sludge concentration.

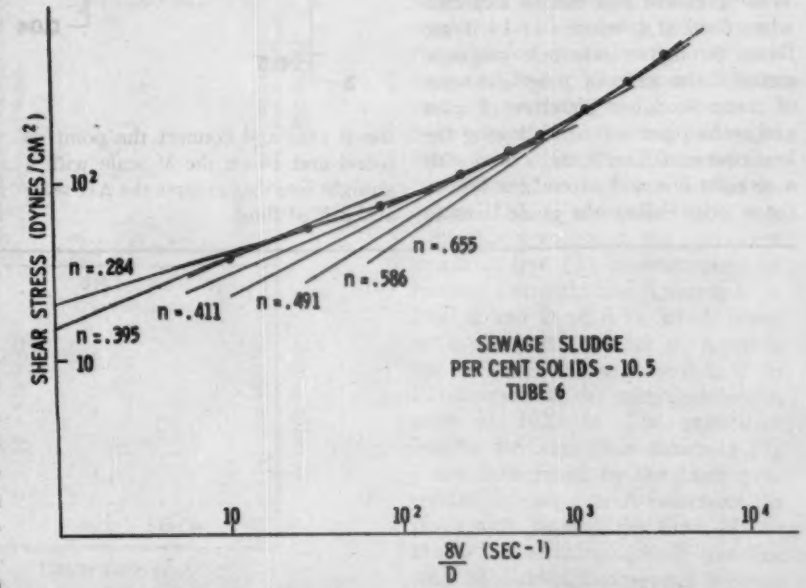


FIG. 5. EXPERIMENTAL RESULTS with 10.5 per cent sludge.

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Pressure Losses in Magnetic Flow Meters

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Univ. of Alabama

■ PRESSURE LOSSES in magnetic flow meters can be calculated from the equations

$$\log (\Delta h + 0.5) = a + b\,R$$

and

$$\Delta H = \Delta h\,(V/10)^2$$

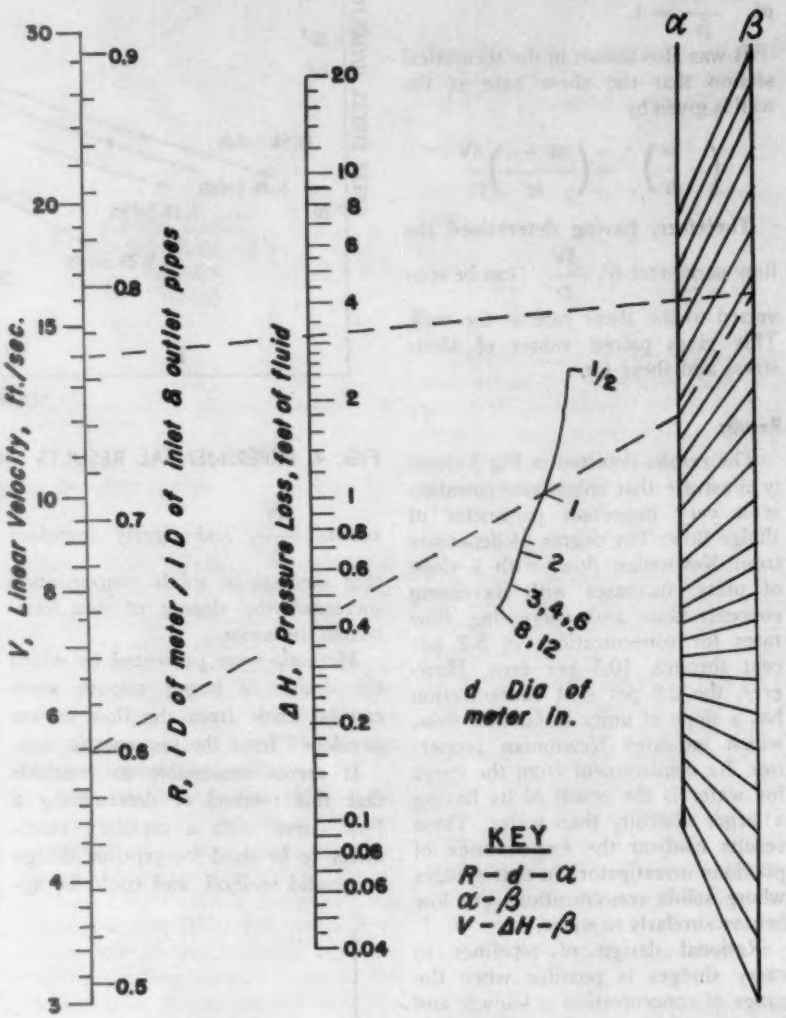
where Δh = pressure loss at a velocity of 10 ft/sec, feet of fluid

R = ratio of inner diameter of meter to inner diameter of inlet and outlet pipes

ΔH = pressure loss at any velocity V ft/sec, feet of fluid

and a and b depend on the diameter of the meter.

These equations are the basis of the accompanying nomograph, which was constructed in accordance with methods described previously[1]. The use of the chart is illustrated as follows: What pressure loss can be expected when fluid at a velocity of 14 ft/sec flows through a one-inch magnetic meter if the ratio of inner diameter of meter to inner diameter of inlet and outlet pipes is 0.6? Following the key, connect 0.6 on R and 1 on d with a straight line and extend the line to the α axis. Follow the guide lines to the β axis and connect the point so found and 14 on the V scale with a straight line that crosses the ΔH scale at 3.2 ft of fluid.



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Nomograph for Equivalent Lengths of Pipe

by ANNABEL TONG

Structural Engineer, Donald E. Stearns P.E., Civil and Sanitary Engineers, Cazenovia, N.Y.

■ IN THE analysis of water main network, the most commonly used method for determining the flow distribution is the Hardy Cross method which is based on the Hazen-Williams formula:

$$V = C R^{0.63} S^{0.54} 0.001^{-0.54}$$

where V = velocity of flow in fps, R = hydraulic radius in f, S = slope of pipe, C = coefficient of friction.
This formula may also be written as follows:

$$h' = \frac{Q^{1.85} L}{17076\, C^{1.85} D^{4.85}} \qquad (1)$$

where L = actual length of pipe in ft, h = friction head in ft = S•L, D = diameter of pipe in ft = 4R, Q = flow in gpm

Equivalent Length

To simplify equation [1], one may introduce an equivalent length which is defined by

$$EL = L\left(\frac{100}{C}\right)^{1.85}\left(\frac{.67}{D}\right)^{4.85} \qquad (2)$$

Substituting equation [2] into equation [1], the friction head becomes

$$h = \frac{EL \times Q^{1.85}}{119 \times 10^{6}} \qquad (3)$$

EL represents the equivalent length of pipe in an ideal water network where the C value throughout the entire system is 100 and the diameter of every pipeline is 8 in. The important aspect of the equivalent length is that it expresses the combined effect of length L, diameter D and the C value of the pipe. Any combination of L, D and C which produces a given equivalent length, will have the same hydraulic effect on the network in question as any other combination of L, D and C values which produces the same value of equivalent length.

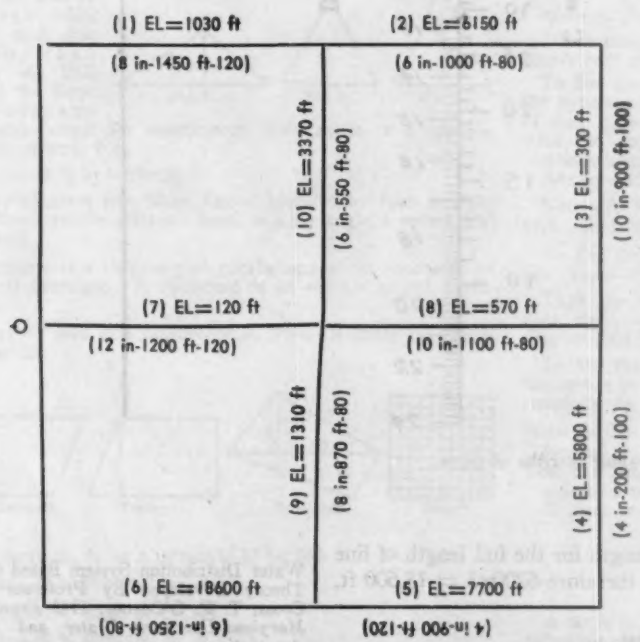


FIG. 1. ILLUSTRATIVE pipe grid with possible values for D, L, and C.

Network Analysis

To analyze a water network system by Hardy Cross method, one assumes a trial value of the flow Q in each line then uses the equivalent length instead of the actual length of the pipelines to calculate the head loss h of each line with equation [3] rather than [1]. Corrections are then applied to the assumed Q and the process is repeated until the hydraulic pressure in every loop of the system is balanced. In comparing equation [3] with equation [1] it is seen than a large portion of the tedious computations is eliminated especially since a procedure of cut and trial is employed in this case.

The nomograph shown in Fig 2 will solve equation [2] for pipeline lengths ranging from 50 ft to 10,000 ft. The scale for equivalent length or true length L on this chart can be read to an accuracy within 5 percent except for the higher values near the end of the scale. For practical purposes this degree of accuracy is sufficient to be in line with the accuracy required for general water network analysis. Fig 1 illustrates a water network consisting of four loops and twelve pipe lines, having values of diameter D, length L and friction coefficient C as indicated in the sequence D-L-C alongside each line. From the nomograph the equivalent length of line (1) is determined by running a straight line A across L = 1450 ft and D = 8 in. which intersects the pivot axis at 0. Another line B is then drawn from 0 to C = 120 intersecting the equivalent length scale at 1030 ft. The equivalent lengths for other lines shown in Fig 1 are determined by the same procedure. In case line A intersects the pivot axis beyond the limit of the chart, the actual length of this line may be divided into several sections so that the problem can be worked

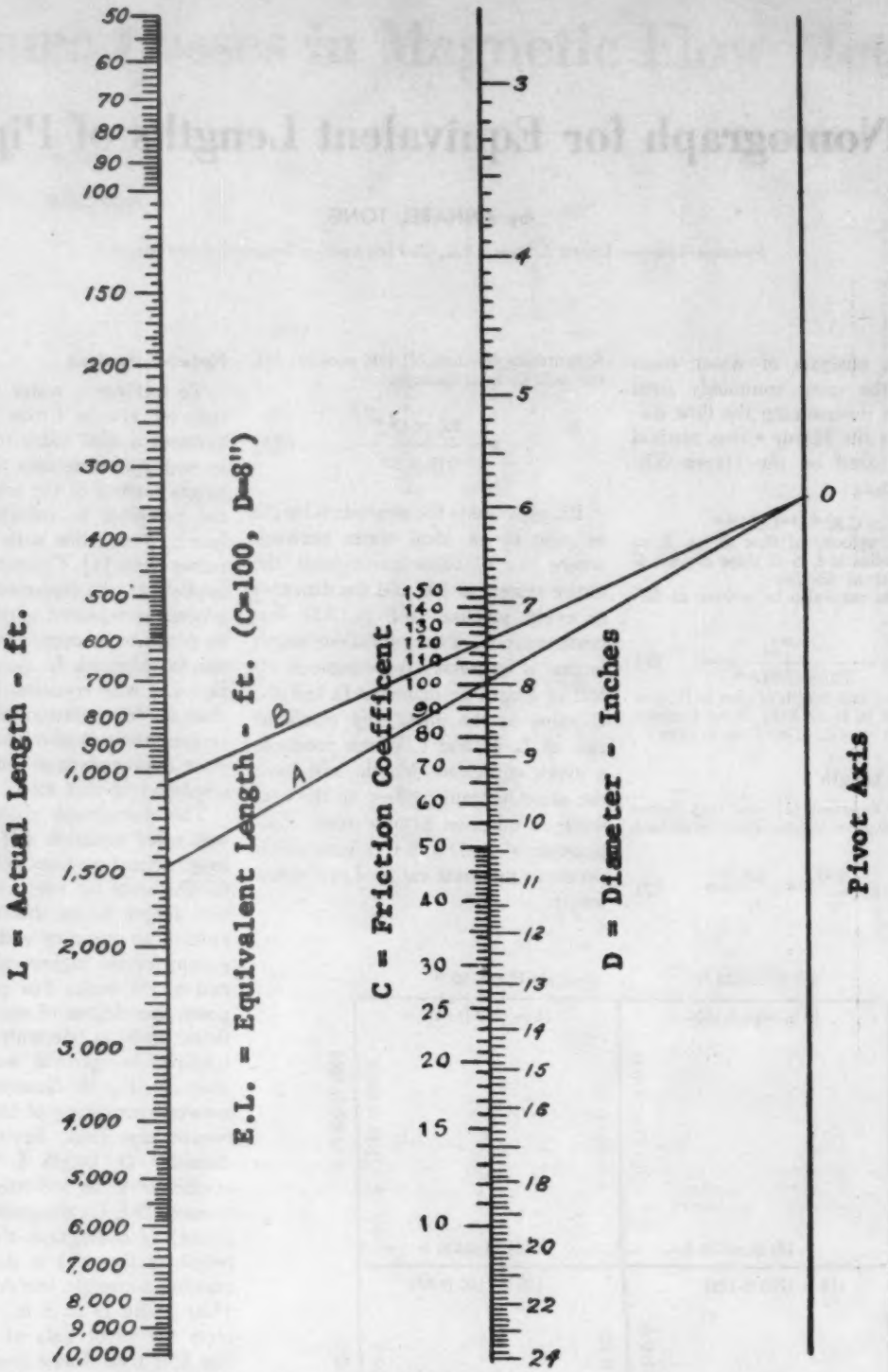


FIG. 2. NOMOGRAPH for Equivalent lengths of pipe.

out in the central region of the chart. For example, line (6) in Fig 1 has L = 900 ft and D = 4 in. Using Fig 2, one finds the equivalent length for 4 in.-300 ft-120 is 6200 ft. The equivalent length for the full length of line (6) is therefore 6200x3 = 18,600 ft.

References

1. A Rapid Method of Analyzing Flow in Water Distribution System Based On The Theory Developed By Professor Hardy Cross, T. F. O'Connor, 1943 *Proceedings, Maryland-Delaware Water and Sewage Association.*

Calculation of Areas, Volumes, Surfaces Reduced to Simple Terms

Mensuration is arithmetic applied to geometry in determining the length of lines, the area of surfaces, and the volume of solids or bodies.

Definitions of geometrical terms, figures and principles. A point (.) has position only. A line (———) has length only. Area has length and breadth. A solid has length, breadth and thickness. Parallel means extended in the same direction, and equidistant at all points. Horizontal means parallel with water level; vertical or perpendicular, parallel with plumb line; diagonal, obliquely across a polygon. (Fig. 4.) Equilateral means, having equal sides. Quadrilateral, having four sides. An angle (Fig. 1) is formed by two straight lines diverging from a common point called the vertex. A right angle (Fig. 2) is formed by two straight lines meeting perpendicularly. An oblique angle is either (acute—Fig. 1) smaller, or (obtuse—Fig. 3) greater than a right angle.

Fig. 1. Fig. 2. Fig. 3. Fig. 4. Rectangle. Parallel Lines.

A plane or plane figure has area or surface only—perfectly even.

A polygon is a plane figure having three or more equal sides.

A triangle is a plane figure bounded by three straight lines.

An equilateral triangle (Fig. 6) has all of its (3) sides equal. An isosceles triangle (Fig. 7) has two of its sides equal. A scalene triangle (Fig. 5) has none of its sides equal. The base is the side on which a geometrical figure is supposed to stand. The least distance between the base and the opposite angle dotted line (Fig. 7) or between parallel lines (Fig. 8) is called the perpendicular or altitude.

To find the area of a triangle. Rule—Multiply base by the altitude and take half of the product. Or, when the three sides are given. From half of the sum of the three sides, subtract each side separately; then multiply the half sum and the three remainders together and extract the square root. Find sq. ft. in a triangle, base 8 ft., altitude 9 ft.

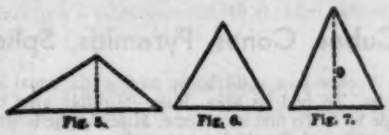


Fig. 5. Fig. 6. Fig. 7.

Answer—$(8 \times 9) \div 2 = 36$.

A parallelogram is a plane figure, bounded by four straight lines, whose opposite sides are equal, as a rectangle, a square, and a rhomboid.

A rectangle is a right angled parallelogram. A square is an equilateral rectangle. A rhomboid is an oblique angled parallelogram.

To find the area of a parallelogram. Rule—Multiply the length by the width.

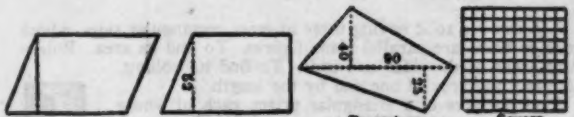


Fig. 8. Rhomboid. Trapezoid. Trapezium. Square

How many sq. ft. in a rectangle 17 by 24?

Answer—$17 \times 24 = 408$ sq. ft.

In a (square) floor 10 by 10?

Answer—$10 \times 10 = 100$ sq. ft.

Note—Dividing the area of a rectangle by one side gives the other side—if unknown.

A *trapezoid* is a quadrilateral having two of its sides parallel. To find its area. Rule—Multiply its average length by the width.

How many sq. yd. in a garden whose parallel sides are 60 and 80 yd., and width 52 yd.?

Answer—$(60 + 80 \div 2) = 70$; then, $70 \times 52 = 3{,}640$ sq. yd.

A *trapezoid* is a quadrilateral having two of its sides parallel.

To find its area. Rule—Form two triangles by a diagonal line, then multiply diagonal by sum of perpendiculars and take half of product.

Find sq. rods in field shaped like a trapezium, whose diagonal is 90 rods, and perpendiculars (25 and 40) 65 rd.

Answer—$90 \times 65 = 5850 \div 2 = 2925$ rd.

A *rightangled triangle* has one right angle. Its longest side is called hypotenuse, and the other two, base and perpendicular or altitude. To find its area. Rule—Multiply the base by the perpendicular and take half of the product.

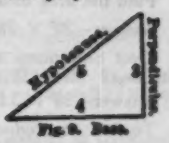


Fig. 9. Base.

How many square rods in a triangular field whose base is 70 rods and the perpendicular, 48 rods?

Answer — $(70 \times 48) \div 2 = 1680$ square rods.

Properties of the rightangled triangle. The square of the hypotenuse equals the sum of the squares of the base and the perpendicular. From this principle—illustrated by Fig. 10—we derive the following rules.

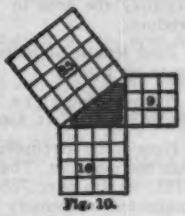


Fig. 10.

To find the hypotenuse. Rule—Add the square of the base and the square of the perpendicular, and of the sum extract square root.

A and B start from the same point, A going 4 miles due west and B, 3 miles due north; how far apart are they then?

$4^2 = 16$
$3^2 = 9$
$\sqrt{25} = 5$

Answer—5 miles.

The square of 4 (base)=16; of 3 (perpendicular)=9; the square root of their sum (25)=5, the hypotenuse.

To find the base or perpendicular. Rule—From the square of the hypotenuse, subtract the square of the other given side, and of their difference extract the square root.

Find the perpendicular of a triangular field whose hypotenuse is 75 rods, base 60 rods. Answer—45 rods.

$75^2 = 5625$
$60^2 = 3600$
$\sqrt{2025} = 45$

Note—To find the difference between the squares of two numbers, simply multiply their sum by their difference.

To find the side of a square equal in area to any given quantity. Rule—Extract the square root of the given quantity.

Thus, the dimensions of a square field containing 4000 square rods must be ($\sqrt{4000} = 63.246$) 63¼ rods, nearly. Proof: $63\frac{1}{4}^2 = 4000+$

To find the diagonal of a square. Rule—Multiply one side of the square by 10, diminish the product by 1% of itself and divide remainder by 7.

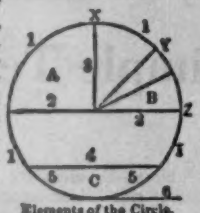
What is the diagonal of a field 35 rods square?
This is a simple way of finding the hypotenuse of a triangle whose base and perpendiculars are equal.

$35 \times 10 = 350$,
1% of 350 = 3.5
7)346.5
Ans. (rd.) 49.5

The Circle

A circle is a plane figure bounded by a curved line, (1, 1, 1, 1) called circumference, every point of which is equally distant from

the center. The diameter is a straight line (2, 2) across a circle, through its center. The radius is a straight line (3) from the center to the circumference. An arc is any part of the circumference (5, 5). A chord, a straight line (4) joining ends of an arc. A tangent (6) touches circum. without cutting it. A segment is space (C) enclosed by arc and chord. A sector, space (B) enclosed by two radii and arc. A quadrant (A) is 90° or the fourth part of circle. A circle is divided into 360°; from X to Y is 45°; from X to Z, 90°. A sextant is one-sixth of a circle.



Elements of the Circle.

To find the *circumference* of a circle, the diameter being given. Rule—Multiply the diameter by 3 1/7; for greater accuracy, by 3.1416.

Find circumference of bicycle wheel; diam. 28 in.

Answer—28 × 3 1/7 = 88 in.

To find the *diameter* of a circle, the circumference being given. Rule—Divide the circumference by 3 1/7, or multiply it by .3183.

Circumference of a tree 144½ in., find diam.

Answer—144.5 × 3183 = 46 in.

To find the *area* of a circle. Rule—Multiply the square of the diameter by .7854; or the square of the radius by 3.1416; or the square of the circumference by .07958.

Find the area of a piston 20 in. in diam.

Answer—20^2 × .7854 = 314.16 sq. in.

Over how many sq. ft. can a cow graze, staked to a rope 50 ft. long? Here, 50 feet is the radius.

Answer—50^2 × 3.1416 = 7854 sq. ft.

To find the *radius* of a circle, the area being given. Rule—Multiply the area by .3183 and extract the square root of the product.

Find length of halter, tied to stake, that will enable horse to graze on 1 acre.

Answer—Square feet in acre, 43560 × .3183 = 13865; √13865 = 117¾ ft. long.

Note—The circumference of a circle is 3.1416 times greater than the diameter. The number 3.1416 (called Pi); its reciprocal, .3183; its 4th part .7854, its 6th part .5236, and others, should be committed to memory as they are indispensable factors in computing the areas and volumes of circular figures and bodies.

To find the *area of a sector* of a circle. Rule—Take such a part of the circle as the degrees in the given arc, are part of 360. Thus, a sector whose arc is 40°, contains 40/360 or 1/9 of the area of the circle.

To find the side of the greatest square that can be inscribed in a given circle. Rule—Multiply the diameter of the circle by .707; or the circumference by .225.

The diameter of a log is 24 inches; how large a sill can be cut from it?

24 × .707 = 17 in. square, nearly.

To inscribe the greatest equilateral triangle. Rule—Multiply the diameter of the circle by .886.

Side of greatest inscribed hexagon equals the radius of a circle.

To find the diameter of a circle that will inscribe a given square. Rule—Multiply the side of the desired square by 1.414.

What must be diam. of a log to cut a sill 12 in. sq.?

Answer—12 × 1.414 = 17 in.

The area of the greatest square inscribed in a given circle is exactly ½ of the area of the least square circumscribed about the same circle—or the square of its diameter.

To find the area between the two *concentric circles*. Rule—Take the difference between the area of each circle. A simpler way is to multiply the sum of the two diameters by their difference, and the product by .7854.

Find the area included between two concentric circles whose diameters are 30 and 50 inches. (80, sum; 20, dif)

Answer—20 × 80 = 1600 × .7854 = 1256.64 sq. in.

To find the diameter of a circle whose area is equal to the area of a given square. Rule—Multiply one side of the given square by 1.1284.

To find the side of a square whose area is equal to the area of a given circle. Rule—Multiply the diameter of the given circle by .8862

To find the diameter of three greatest equal circles that can be inscribed in a given circle. Rule—Multiply the diameter of the given circle by .464.

Find the diameters of the three greatest circles that can be inscribed in a circle 50 in. in diam.

Answer—50 × .464 = 23.2 in.

An *ellipse* is a plane figure bounded by an oval curved line and has a long and a short diameter or axis.

To find its circumference. Rule—Multiply the sum of the two diameters by 3.1416, and take half of the product.

Ellipse.

Find the circumference of an ellipse whose diameters are .41 and 29 ft.

(41 + 29) = 70 × 3.1416 ÷ 2 = 110 ft. nearly.

To find the *area of an ellipse*. Rule—Multiply the product of the two diameters by .7854.

How many square ft. are there in an elliptical platform whose diameters are 60 and 40 ft.?

60 × 40 = 2400 × .7854 = 1885 sq. ft. nearly.

Polygons

Triangle. Square. Pentagon. Hexagon. Octagon.

To find the area of polygons, having equal sides and equal angles. Rule—Multiply the square of one of the equal sides—of a triangle, by .433; of a pentagon, by 1.7205; of hexagon, by 2.5981; of octagon, by 4.8284.

One side of an equilateral triangle is 30 inches, and of an octagon. 10 in

Find sq. in. in each.

30^2 × 433 = 389.7 in. T; 10^2 × 4.824 = 482.84 in. O.

Trigonometric Functions.

For the benefit of those who intend to study trigonometry and surveying, this illustration is inserted here. It will be an advantage and saving of time to be already familiar with the terms and the functions of the science when beginning its study.

P M, sine.
O M, cosine.
A T, tangent.
B S, cotangent.
O T, secant.
O S, cosecant.
M A, versed sine.
B N, conversed sine

Cubes, Cones, Pyramids, Spheres,

A *cube* is a solid body, having six equal square sides. To find its area. Rule—Multiply area of one side by 6. To find its volume. Multiply the length, the breadth and the thickness together.

Cube.

Find sq. in. in surface of a 12 in. cube.

Answer—12^2 × 6 = 864.

How many cubic in. in a cubic foot?

Answer—$*12^3$ = 1728.

Find cu. ft. in a cu. mile.

Answer—5280^3 = 147197952000.

A *parallelopiped* is a solid body whose six faces are all rectangles. To find its area Rule—Add areas of its six sides. To find its volume. Same as the cube. How many cubic feet in a wagon bed 10½ feet long, 3 ft. wide and 1¼ ft. deep?

Parallelopiped.

Answer—10½ × 3 × 1¼ = 39⅜.

A *prism* is a solid having three or more rectangular sides, whose ends or bases are parallel plane figures. To find its area. Rule—Add areas of the sides and ends. To find its volume. Multiply the area of one end by the length.

Prism.

Find the area of a triangular prism, each of whose three sides are 10 by 25 inches.

Answers—836.6 sq. in.

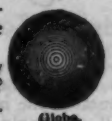
10^2 × .433 × 2 = 86.6 sq. in. in area of the two ends.

10 × 25 × 3 = 750 sq. in. area of sides. 86.0 + 750 = 836.6.

How many cubic inches in above prism. 10 by 25 inches?

Answer—10^2 × .433 = 43.3 × 25 = 1082½ cu. in.

A *globe* or *sphere* is a solid body, bounded by a uniformly curved surface. To find its area. Rule—Multiply the square of diameter by 3.1416; or the square of the circumference by .3183. To find its volume. Multiply the cube of diameter by .5236.


Globe.

How many square in. in the surface; and how many cubic in. in the volume of a globe 12 in. in diameter?

Answer—904.78 cu. in. $12^2 \times 3.1416 = 452.39$ sq. in. $12^3 \times .5236 = 904.78$ cu. in.

How many cubic miles in the earth, its diameter being nearly 8000 miles?

Answer—$2000^3 \times .5236 = 268083200000$ cubic mi.

Find greatest cube inscribed in a 26 in. globe.

Answer—$26 \times .577 = 15$ in.

To find the dimensions of a cube, equivalent in volume to a given globe. Rule—Multiply the diameter of given globe by 806.

To find the diameter of a globe, equivalent in volume to a given cube. Rule—Multiply one side of the cube by 1.2407.

A *cylinder* is a round body of uniform diameter whose ends are parallel plane figures. To find its area. Rule—Multiply the circumference by the length and to the product add the areas of both ends. To find its volume. Multiply the area of one end by length.

Cylinder.

Find the area of a cylinder 30 inches in circumference and 40 inches long.

Answer—1343.24 sq. in.

$30 \times 40 = 1200$ sq. in. in convex surface.

$30^2 \times .07958 \times 2 = 143.24$ sq. in. in the two ends.

Find cubic in. in a cylinder, diameter, 20 in., length 50 in.

Answer—$20^2 \times .7854 \times 50 = 15708$ cu. in.

A *cone* is a solid, which has a circular base and tapers uniformly to a point called vertex.

A *pyramid* is a solid, resembling a cone, having three or more triangular sides.

Cone.

Pyramid.

To find the area of a *cone or pyramid*. Rule—Multiply the circumference or perimeter of the base by the slant height, and to half of the product, add the area of the base.

Find the area or surface of a cone whose circumference at base is 40 in., and slant height 50 in.

Answer—1127.33 sq. in.

$50 \times 40 \div 2 = 1000$ sq. in. in convex surface.

$40^2 \times .07958 = 127.33$ in. base.

To find the volume of a cone or pyramid. Rule—Multiply the area of the base by the height and take ⅓ of the product.

How many cubic feet in a 6 sided pyramid, 10 ft. high, whose perimeter, at base is 15 ft. or each side 2½ ft.?

Answer—54.13 cu. ft.

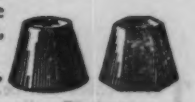
$2\frac{1}{2}^2 \times 2.598 = 16.24$, area of base. $10 \times 16.24 \div 3 = 54.13$.

Find cu. in. in a cone whose height is 12½ in., and diameter of base 10 in.

Answer—$10^2 \times .7854 = 78.54$ area of base. $78.54 \times 12\frac{1}{2} \div 3 = 32.25$ cu. in.

The solid contents of the cone, globe, cylinder and the cube, all of equal dimensions, are in the ratio of 1, 2, 3 and 3.82 respectively. Thus, taking 1 foot as the height and the diameter; the cone contains .2618; the globe .5236, and the cylinder .7854 of a cubic foot. The cube equals 1 cu. ft.

The *frustum of a cone or pyramid* is the part which remains after cutting off the top, parallel to the plane of the base. To find the area of a frustum. Rule—Multiply the sum of circumferences, or perimeters, by the slant height, and to half of the product, add the area of each base.


Frustums.

Find the *area of a frustum* of a cone, whose slant height is 40 in., its greater circumference, 30 in., and its smaller one, 10 in.

Answer—879.58 sq. in.

$30 + 10 \times 40 \div 2 = 800$, sides. $30^2 + 10^2 \times .07958 = 79.58$, area of bases.

To find the *volume of any frustum*. Rule—Square both ends of one side, if angular, or the diameters of both ends or bases, if round. To the two squares add the product of the given ends or diameters; ⅓ of this sum will be the area of the average base of the frustum of a square pyramid, which multiplied by .7854 equals area of average base of frustum of a cone; multiplied by .433, of a three sided frustum, by 1.7205, of a five sided fr., by 2.5981, of a six sided frustum, by 4.8284, of an eight sided frustum. For volume: multiply average area by perpendicular height.

Find the volume or capacity of a round tank whose diameter is 15 ft. at base, 12 ft. at top, and 10 ft. deep. Ans.—14.37 cu. ft.

$12^2 = 144$
$15^2 = 225$
$12 \times 15 = 180$

$183 \times .7854 = 143.73$ sq. ft., area of av. base of Fr. of cone.

3)549(183, area of av. base of F. of sq. pyr.

$143.73 \times 10 = 1437.3$ cu. ft. $\times 7.48 = 10751$ gallons.

Find sq. ft. of lumber in a wagon tongue; large end, 4½ in. sq., small end, 2½ in., length, 9 ft. (108 in.).

Answer—$4\frac{1}{2} + 2\frac{1}{2}^2 + (4\frac{1}{2} \times 2\frac{1}{2}) \div 3 = 12\,7/12$ sq. in., area of average base; $12\,7/12 \times 108 = 1359$ cu. in. $\div 144 = 9\,7/16$ sq. ft.

How many cu. ft. in a straight log, whose diameter at large end is 3 ft., small end, 2 ft., length 12 ft?

Answer—$3^2 + 2^2 + (3 \times 2) \div 3 \times .7854 = 4.974$ sq. ft., area of average base; $4.97_7 \times 12 = 59.69$ cu. ft.

A *spheroid* or elongated globe has a fixed and a revolving axis. To find its area. Rule—Multiply the revolving axis by the fixed axis, and that product by 3.1416. To find its volume. Rule—Multiply the square of the revolving axis by the fixed axis and that product by .5236. Find area, also the volume of spheroid; revolving axis, 20 in., fixed, 30 in.

Spheroid

$20 \times 30 \times 3.1416 = 1884.96$ sq. in. in area.

$20^2 \times 30 \times .5236 = 6283.2$ cu. in. in volume.

A *cylindrical ring* is formed by bending a cylinder. To find its area. Rule—Multiply sum of inside diam. and thickness of ring, by thickness, and the product by 9.87. To find its volume. Rule—Multiply sum of inside diam. and thickness by square of thickness, and product by 2.467.

Ring.

Find the area, also the volume of a ring whose inner diameter is 15 inches, and whose thickness is 5 inches.

$(15 + 5) \times 5 \times 9.87 = 987$ sq. in. in area. $(15 + 5) \times 5^2 \times 2.467 = 1233.5$ cu. in vol.

To find the dimensions of *greatest cube that can be inscribed in a given globe*. Rule—Multiply the diameter of the globe by .577.

The above material has been drawn from "Ropp's Calculator"—an extremely useful and inexpensive little booklet published by C. Ropp & Sons, of Chicago.

Contents of Rectangular Tanks

Cubic Feet, Gallons, Pounds, and Tons of Water

THIS chart will be found useful for rectangular tank determinations. The dimensions of the tank, all in inches, are given in columns A, C, and D. Then, as will be noted, you can find the number of cubic feet in column E, the gallons in column F, the pounds of water in column G, and the tons of water in column H. As a typical example, let us say that the width of a given tank is 10 inches, the depth 5 inches, and the length 20 inches. How many pounds of water will the tank hold?

How to Use the Chart

Find the 10 in column A and run a straight line over to the 5 in column C and locate the intersection with column B. Then from that point of intersection run over to the 20 in column D, and note the intersection with column C. It will be observed now that column C and J are exactly alike so that perfectly horizontal lines can be drawn between those two columns. In this instance the intersection in column C happens to be through the 10, so simply run a straight line through the 10 in column C and the 10 in column J, as shown by the dotted line, and you have a perfectly horizontal line which gives all of the answers as follows:

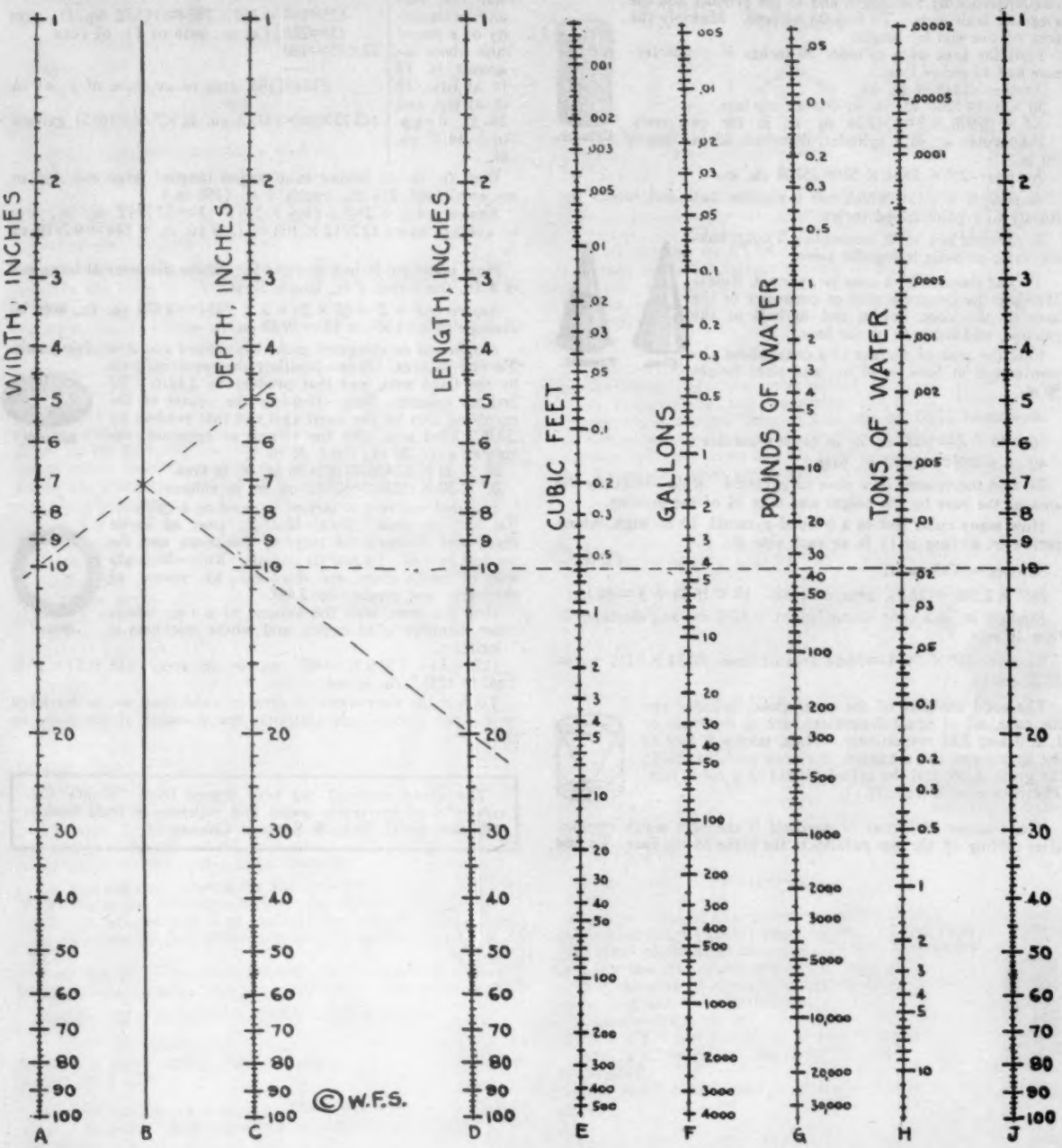
Column E shows that the tank has a volume of nearly 0.6 cu. ft.

Column F shows that the number of gallons is about 4.3.

Column G shows that if the tank contains water the weight will be about 37 pounds.

Column H shows that the number of tons of water is approximately .0185.

Contributed by W. F. Schaphorst, M.E., Newark, N. J.



Contents of Horizontal Cylinders

A Multiple Use Chart for Vertical as Well as Horizontal Tanks, Pipe Lines, Etc.

by J. TARRANT

Assoc. M. Inst. C.E., A.M.I. Mech. E. Ruislip (Middlesex), England

THE alignment chart printed herewith gives a convenient method of finding the contents of cylindrical tanks placed with the axis horizontal for all depths of liquid in the tank.

It is usually the case that only a fair approximation of the tank contents is required, and the calculation by exact formula is not very readily done.

Formulas for horizontal cylindrical tanks contents are generally printed in two forms, one for use when the liquid level is above the centre and the other when the level is below the centre of the tank.

On the chart, the scale relating to the depth of liquid is continuous; that is to say, it applies whether the liquid level be in the upper or lower half of the section.

To use the chart, a straightedge is placed across the scales, and the intersections on the three scales give the related values. Line A gives the ratio of depth of liquid to the diameter of the tank; line B, the diameter of the tank in feet; and line C, the contents, in cubic feet and gallons, for each foot of length of the tank. In the example shown by the line across the chart, a tank 15 feet in diameter in which the contents are 10 feet 6 inches deep, will contain approximately 1,000 gallons per foot of length.

By using the fixed value of h/d = 1, the chart also gives contents per foot of height of a cylinder with vertical axis, and also the contents of full pipes per foot of length.

Sometimes the dimensions of a tank or pipe line will not be in feet, but the chart may still be used. The contents will be in units which correspond to the dimensional units, and the scale of gallons will not apply. For example, if the diameter is taken in inches, the contents, *read on the cubic feet scale*, will be in *cubic inches* per *inch* of length.

The calculation of contents is clearly based on the area of the segment of a circle, which is what the contents scale on line C shows, and the calculation of segmental areas, in any dimensional units, may be made by use of the chart so long as the cubic feet scale is read, and units ascribed to this which correspond to the units used for the diameter. When the diameter is in feet, the area of the segment is in square feet; for meters, the area is in square meters; for inches, in square inches, and so on.

WEIGHTS AND MEASURES

Troy Weight

3.086 grains = 1 carat
24 grains = 1 dwt.
20 dwts. = 1 ounce
12 ounces = 1 pound

Used for weighing gold, silver, and jewels.

Apothecaries' Weight

20 grains = 1 scruple
3 scruples = 1 dram
8 drams = 1 ounce
12 ounces = 1 pound

The ounce and pound in this weight are the same as in Troy Weight.

Avoirdupois Weight

1 grain (Troy) = 1 grain (Apoth.) = 1 grain (Avdp.)

27 11/32 grams = 1 dram
16 drams = 1 ounce = 437.5 grains
16 ounces = 1 pound
25 pounds = 1 quarter
4 quarters = 1 cwt.
2,000 lbs. = 1 short ton
2,240 lbs. = 1 long ton
1 long ton = 1 British ton

Dry Measure

2 pints = 1 quart
1 quart = 67.2 cu. in.
1 British bushel = 1.032 U. S. Bushel
8 quarts = 1 peck
4 pecks = 1 bushel

Liquid Measure

4 gills = 1 pint
16 fluid ounces = 1 pint
2 pints = 1 quart
4 quarts = 1 gallon
1 British Imperial gallon = 1.200 U. S. gallons
1 cubic foot of water contains 7.48 gallons and weighs 62.321 lb.
1 gallon = 231 cu. in.
31½ gallons = 1 barrel
2 barrels = 1 hogshead

Linear Measure

1 mil = 0.001 inch
12 inches = 1 foot
3 feet = 1 yard
5½ yards = 1 rod
40 rods = 1 furlong
8 furlongs = 1 statute mile
5280 feet = 1 statute mile
3 miles = 1 league

Square Measure

1 circular mil = 0.7854 square mils
1,000,000 square mils = 1 square inch
144 square inches = 1 sq. ft.
9 sq. ft. = 1 sq. yard
4 roods = 1 acre = 43560 sq. ft.
30¼ sq. yds. = 1 sq. rod
40 sq. rods = 1 rood
640 acres = 1 sq. mile

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7.92 inches = 1 link
25 links = 1 rod
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10 sq. chains or 160 sq. rods = 1 acre
36 sq. miles (6 miles square) = 1 township

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6.08 feet = 1 fathom
120 fathoms = 1 cable length
8.31 cable lengths = 1 nautical mile
6080 feet = 1 nautical mile
1 nautical mile = 1.15 statute mile
1 knot is a speed of 1 nautical mile per hour

Paper Measure

24 sheets = 1 quire
20 quires = 1 ream
2 reams = 1 bundle
5 bundles = 1 bale

Cubic Measure

1 cu. cm. = .061 cu. in.
27 cu. ft. = 1 cp. yd.
40 cu. ft. = 1 ton (shipping)
231 cu. in. = 1 standard gallon
2150.42 cu. in. = 1 standard bushel
1 cu. ft. = 4/5 of a bushel
1728 cu. in. = 1 cu. ft.
128 cu. ft. = 1 cord (wood)

Household Measure

60 drops = 1 teaspoon
2 teaspoons = 1 dessert spoon
3 teaspoons = 1 tablespoon
16 tablespoons = 1 cup
2 gills = 1 cup
2 cups = 1 pint

METRIC EQUIVALENTS

Linear Measure

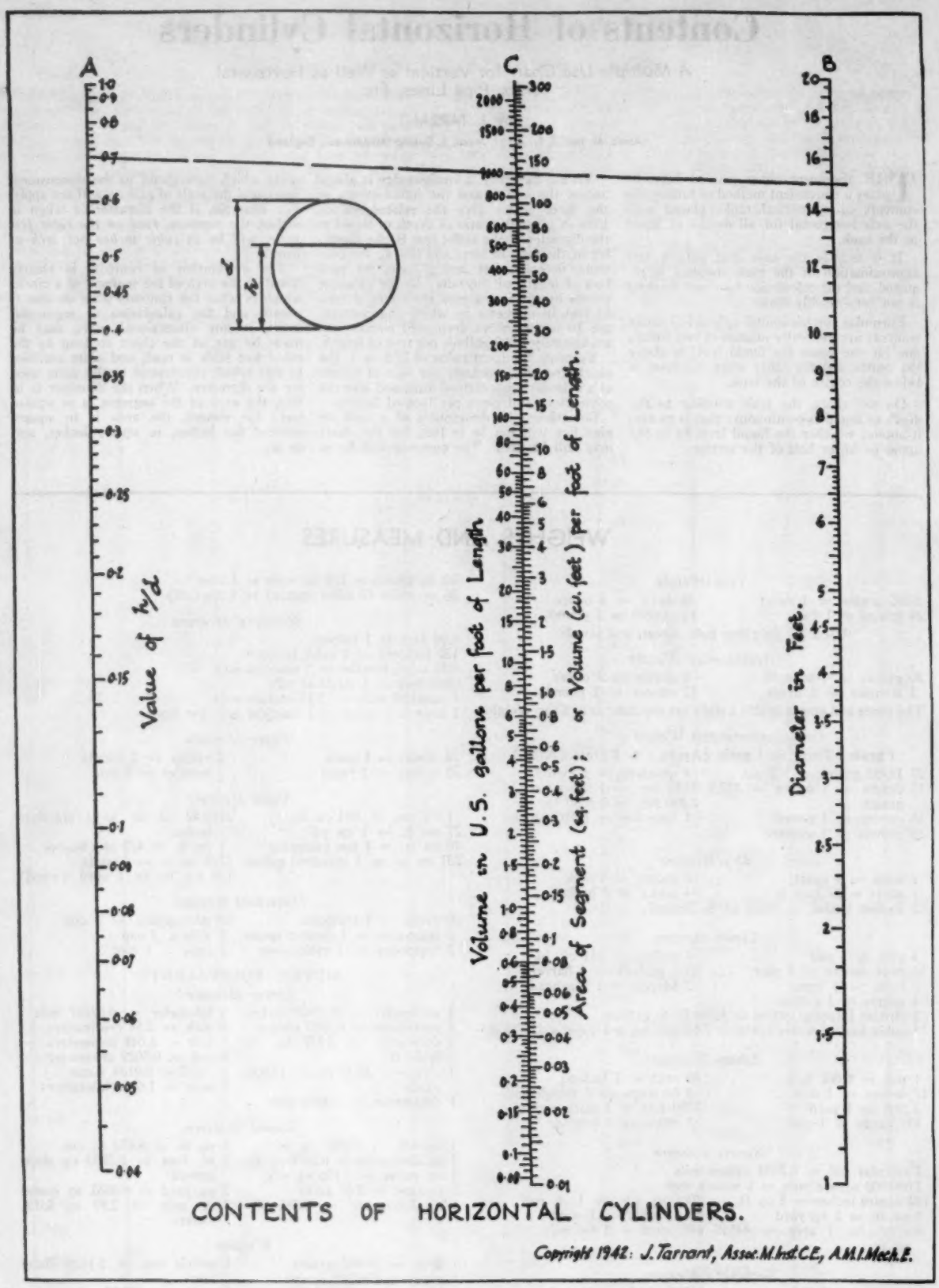
1 millimeter = 0.03937 inches
1 centimeter = 0.3937 inches
1 decimeter = 3.937 in. = 0.328 ft.
1 meter = 39.37 in. = 1.0936 yards
1 dekameter = 1.9884 rods
1 kilometer = 0.62137 mile
1 inch = 2.54 centimeters
1 foot = 3.048 decimeters
1 rod = 0.5029 dekameter
1 yard = 0.9144 meter
1 mile = 1.6093 kilometers

Square Measure

1 sq. cm. = 0.1550 sq. in.
1 sq. decimeter = 0.1076 sq. ft.
1 sq. meter = 1.196 sq. yds.
1 hectare = 2.47 acres
1 sq. kilometer = 0.386 sq. miles
1 sq. in. = 6.452 sq. cm.
1 sq. foot = 9,2903 sq. decimeters
1 sq. yard = 0.8361 sq. meter
1 sq. mile = 2.59 sq. kilometers

Weights

1 dyne = .00102 grains
1 gram = 0.03527 ounces
1 kilogram = 2.2046 lbs.
1 metric ton = 2205 lbs.
1 pound = 0.4536 kilograms
1 metric ton = 1.1023 short tons
1 ounce = 28.35 grams = 437.5 grains



CONTENTS OF HORIZONTAL CYLINDERS.

Copyright 1942: J. Tarrant, Assoc. M. Inst. C.E., A.M.I. Mech. E.

NOTE THE NUMBERS

they correspond with the

headings on

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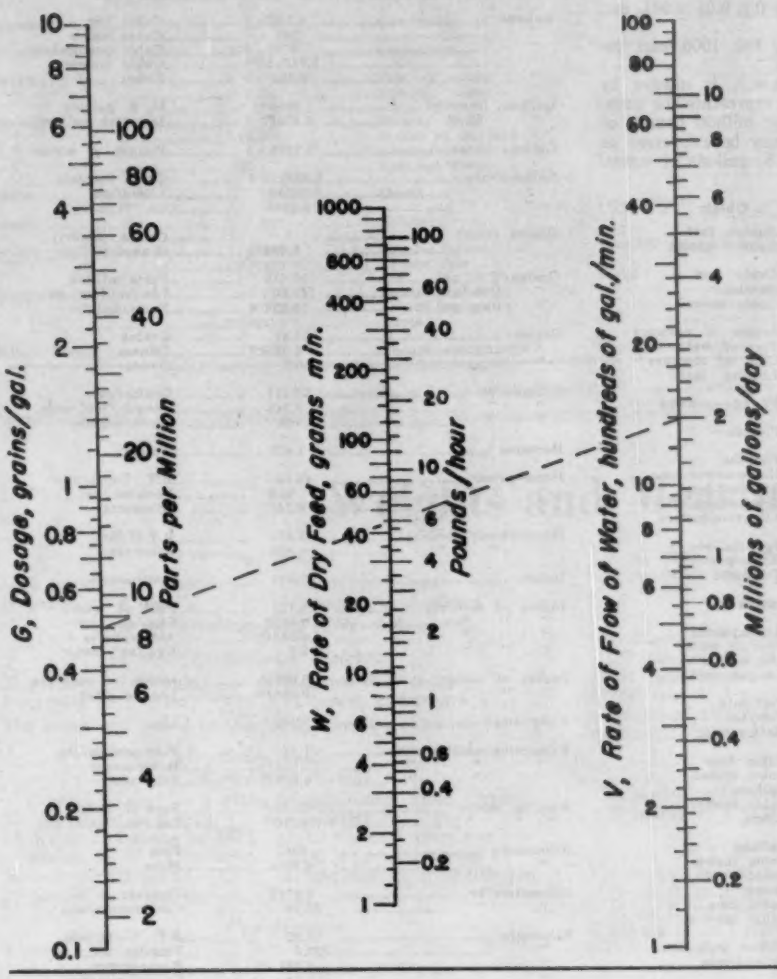
Bulletins and Catalogs

JUST CLIP THESE CARDS MARK AND MAIL— TO RECEIVE THE BULLETINS AND CATALOGS LISTED IN THIS ISSUE

WATER & SEWAGE WORKS

Nomograph For Dry Chemical Feeds

D. S. Davis
Univ. of Alabama


G, Dosage, grains/gal.
Parts per Million
W, Rate of Dry Feed, grams/min.
Pounds/hour
V, Rate of Flow of Water, hundreds of gal./min.
Millions of gallons/day

■ THE RATE of dry feed, for water treatment, is given by the equation

$$w = 6.46\ G\ V$$

where w = rate of dry feed, grams/min
G = dosage, grains/gal
V = rate of flow of water, hundreds of gallons/min.

The accompanying nomograph enables one to solve this equation readily and accurately, and was constructed in accordance with methods described previously[1]. Doubly graduated scales cover the alternative units of pounds of feed per hour, parts of dosage per million parts of water, and rate of flow of water in millions of gallons of water per day.

The broken index line shows that rates of dry feed of 45 grams/min or 6 lb/hr are achieved when the dosage is 0.5 grain/gal or 8.6 parts/million and the rates of flow of water are 1400 gal/min or 2.02 millions of gallons/day.

Reference

[1] Davis, D. S., "Nomography and Empirical Equations," Chap. 6, Reinhold Publishing Company, New York, 1955.

Conversion Factors

The word gallon, used in any conversion factor, designates the U.S. gallon. Likewise, the word ton designates a short ton, 2,000 pounds.

The figures 10^{-1}, 10^{-2} 10^{-3}, etc., denote 0.1, 0.01, 0.001, etc., respectively.

The figures 10^{1}, 10^{2}, 10^{3}, etc., denote 10, 100, 1000, etc., respectively.

"Parts Per Million," (designated as p.p.m.), is always by weight. As used in the sanitary field, p.p.m. represents the number of pounds of dry solids contained in one million pounds of water. In this field, one part per million may be expressed as 8.345 pounds of dry solids to one million U.S. gallons of water.

Multiply	By	To Obtain
Acres	43,560	Square feet
"	4,047	Square meters
Acre-feet	43,560	Cubic feet
" "	325,851	Gallons
" "	1233.49	Cubic meters
Atmospheres	29.92	Inches of mercury
"	33.90	Feet of water
"	76.0	Cms. of mercury
"	14.70	Lbs./sq. inch
Barrels cement	376	Pounds—cement
Bags or sacks-cement	94	Pounds— "
British Thermal Units	777.5	Foot-lbs.
" " "	3.927×10^{-4}	Horse-power-hrs.
" " "	2.928×10^{-4}	Kilowatt-hrs.
" " "	0.2520	Kilogram-calories
" " "	107.5	Kilogram-meters
B.T.U./min.	12.96	Foot-lbs./sec.
" "	0.02356	Horse-power
" "	0.01757	Kilowatts
Centimeters	0.3937	Inches
Centimeters of mercury	0.01316	Atmospheres
" " "	0.4461	Feet of water
" " "	27.85	Lbs./sq. ft.
" " "	0.1934	Lbs./sq. inch
Centimeters/second	1.969	Feet/min.
" "	0.03281	Feet/sec.
" "	0.6	Meters/min.
Cubic centimeters	3.531×10^{-5}	Cubic feet
" "	6.102×10^{-2}	Cubic inches
" "	2.642×10^{-4}	Gallons
" "	10^{-6}	Cubic meters
" "	10^{-3}	Liters
Cubic feet	7.48052	Gallons
" "	1728	Cubic inches
" "	0.03704	Cubic yards
" "	28.32	Liters
" "	2.832×10^{4}	Cubic cms.
" "	0.02832	Cubic meters
Cubic feet/second	0.646317	Million gals./day
" " "	448.831	Gallons/min.
Cubic inches	16.39	Cubic centimeters
" "	5.787×10^{-4}	Cubic feet
" "	1.639×10^{-5}	Cubic meters
" "	4.329×10^{-3}	Gallons
" "	1.639×10^{-2}	Liters
Cubic meters	35.31	Cubic feet
" "	1.308	Cubic yards
" "	264.2	Gallons
" "	10^{3}	Liters
Cubic yards	27	Cubic feet
" "	46.656	Cubic inches
" "	0.7646	Cubic meters
" "	202.0	Gallons
" "	764.6	Liters
Drams	27.34375	Grains
"	0.0625	Ounces
"	1.771845	Grams
Fathoms	6	Feet
Feet	30.48	Centimeters
"	0.3048	Meters
Feet of water	0.8826	Inches of mercury
" " "	0.4335	Lbs./sq. inch
" " "	62.43	Lbs./sq. ft.
" " "	0.02950	Atmospheres
" " "	304.8	Kgs./sq. meter
Feet/sec.	30.48	Centimeters/sec.
" "	18.29	Meters/min.
Foot-pounds	1.286×10^{-3}	British thermal units
" "	5.050×10^{-7}	Horse-power-hrs.
" "	0.1383	Kilogram-meters
" "	3.766×10^{-7}	Kilowatt-hrs.
Foot-pounds/min.	3.030×10^{-5}	Horse-power
" " "	2.260×10^{-5}	Kilowatts
Gallons	0.1337	Cubic feet
"	231	Cubic inches
"	3785	Cubic centimeters
"	3.785×10^{-3}	Cubic meters
"	3.785	Liters
Gallons, Imperial	1.200095	U. S. gallons
" U. S.	0.83267	Imperial gallons
Gallons water	8.3453	Pounds of water
Gallons/min.	2.228×10^{-3}	Cubic feet/sec.
" "	0.06308	Liters/sec.
" "	8.0208	Cu. ft./hr.
Grains (troy)	1	Grains (avoir.)
"	0.06480	Grams
Grains/U.S. gal.	17.118	Parts/million
" /U.S. gal.	142.86	Lbs./million gal.
" /Imp. gal.	14.254	Parts/million
Grams	15.43	Grains
"	0.03527	Ounces
"	980.7	Dynes
Grams/liter	58.417	Grains/gal.
" "	8.345	Pounds/1000 gals.
" "	1000	Parts/million
Hectares	2.471	Acres
Horse-power	42.44	B.T. Units/min.
" "	550	Foot-lbs./sec.
" "	0.7457	Kilowatts
Horse-power (boiler)	33.479	B.T.U./hr.
" " "	9.803	Kilowatts
Inches	2.540	Centimeters
Inches of mercury	1.133	Feet of water
" " "	0.4912	Lbs./sq. inch
" " "	0.03342	Atmospheres
" " "	345.3	Kgs./sq. meter
Inches of water	0.07355	Inches of mercury
" " "	0.03613	Lbs./sq. inch
Kilograms	2.205	Lbs.
Kilograms-calories/min.	51.43	Foot-pounds/sec.
" " "	0.09351	Horse-power
" " "	0.06972	Kilowatts
Kgs./sq. meter	3.281×10^{-3}	Feet of water
" " "	1.422×10^{-3}	Lbs./sq. inch
Kilometers	3281	Feet
"	0.6214	Miles
Kilometers/hr.	0.9113	Feet/sec.
" "	27.78	Centimeters/sec.
Kilowatts	56.92	B.T. Units/min.
"	737.6	Foot-lbs./sec.
"	1.341	Horse-power
"	14.34	Kg.-calories/min.
Liters	0.2642	Gallons
"	61.02	Cubic inches
"	0.03531	Cubic feet
Meters	3.281	Feet
"	39.37	Inches
"	1.094	Yards
Miles	5280	Feet
"	1.609	Kilometers
Miles/min.	88	Feet/sec.
" "	1.609	Kilometers/min.
Milligrams/liter	1	Parts/million
Million gals./day	1.54723	Cubic ft./sec.
Miner's inches	1.5	Cubic ft./min.
Ounces	28.349527	Grams
"	437.5	Gains
"	0.9115	Ounces (troy)
Ounces (fluid)	1.805	Cubic inches
" "	29.57	Cubic cm.
Parts/million	8.345	Lbs./million gal.
" "	0.0584	Grains/U. S. gal.
" "	0.07016	Grains/Imp. gal.
Pounds	16	Ounces
"	7000	Grains
"	453.5924	Grams
"	1.21528	Pounds (troy)

Selections from a booklet of—"Conversion Factors for Engineers"—distributed by The Dorr Co., Stamford, Conn.

Multiply	By	To Obtain
Pounds of water	0.01602	Cubic feet
" " "	27.68	Cubic inches
" " "	0.1198	Gallons
Pounds/cubic foot	0.01602	Grams/cubic cm.
" " "	16.02	Kgs./cubic meter
" " "	5.787×10^{-4}	Lbs./cubic inch
Pounds/foot	1.488	Kgs./meter
Pounds/inch	178.6	Grams/cm.
Pounds/sq. foot	0.01602	Feet of water
" " "	4.883	Kgs./sq. meter
Pounds/sq. inch	2.307	Feet of water
" " "	2.036	Inches of mercury
" " "	0.06804	Atmospheres
" " "	703.1	Kgs./sq. meter
Quires	25	Sheets
Reams	500	Sheets
Square centimeters	0.1550	Square inches
" "	1.076×10^{-3}	Square feet
Square feet	144	Square inches
" "	0.09290	Square meters
" "	2.296×10^{-5}	Acres
Square inches	6.452	Square centimeters
Square kilometers	247.1	Acres
" "	10.76×10^{6}	Square feet
" "	1.196×10^{6}	Square yards
Square meters	10.76	Square feet
" "	1.196	Square yards
Square miles	640	Acres
" "	27.88×10^{6}	Square feet
" "	2.590	Square Kilometers
Square yards	9	Square feet
" "	0.8361	Square meters
" "	2.066×10^{-4}	Acres
Tons (long)	1016	Kilograms
" "	2240	Pounds
" "	1.12000	Tons (short)
Tons (metric)	10^{3}	Kilograms
" "	2205	Pounds
Tons (short)	2000	Pounds
" "	907.18486	Kilograms
Tons of water/24 hrs.	0.16643	Gallons/min.
Watts	0.05692	B.T. Units/min.
"	0.7376	Foot-pounds/sec.
"	1.341×10^{-3}	Horse-power
"	0.01434	Kg.-calories/min.
Yards	0.9144	Meters

Conversion of °C to °F or °F to °C = $\frac{C}{100} = \frac{F - 32}{180}$

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3.086 grains = 1 carat
24 grains = 1 dwt.
20 dwts. = 1 ounce
12 ounces = 1 pound

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2,240 lbs = 1 long ton
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31½ gallons = 1 barrel
2 barrels = 1 hogshead

1 British Imperial gallon = 1.200 U.S. gallons
1 cubic foot of water contains 7.48 gallons and weighs 62.321 lb.

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1 mil = 0.001 inch
12 inches = 1 foot
3 feet = 1 yard
5½ yards = 1 rod
40 rods = 1 furlong
8 furlongs = 1 statute mile
5280 feet = 1 statute mile
3 miles = 1 league

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1 circular mil = 0.7854 square mils
1,000,000 square mils = 1 square inch
144 square inches = 1 sq. ft.
9 sq. ft. = 1 sq. yard
4 roods = 1 acre = 43560 sq. ft.
30¼ sq. yds. = 1 sq. rod
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640 acres = 1 sq. mile

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25 links = 1 rod
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43560 sq. ft. = 1 acre
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36 sq. miles (6 miles square) = 1 township

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6.08 feet = 1 fathom
120 fathoms = 1 cable length
8.31 cable lengths = 1 nautical mile
6080 feet = 1 nautical mile
1 nautical mile = 1.15 statute mile
1 knot is a speed of 1 nautical mile per hour

Paper Measure

24 sheets = 1 quire
20 quires = 1 ream
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5 bundles = 1 bale

Cubic Measure

1 cu. cm. = .061 cu. in.
27 cu. ft. = 1 cp. yd.
40 cu. ft. = 1 ton (shipping)
231 cu. in. = 1 standard gallon
2150.42 cu. in. = 1 standard bushel
1 cu. ft. = ⅘ of a bushel
1728 cu. in. = 1 cu. ft.
128 cu. ft. = 1 cord (wood)

Household Measure

60 drops = 1 teaspoon
2 teaspoons = 1 dessert spoon
3 teaspoons = 1 tablespoon
16 tablespoons = 1 cup
2 gills = 1 cup
2 cups = 1 pint

METRIC EQUIVALENTS

Linear Measure

1 millimeter = 0.03937 inches
1 centimeter = 0.3937 inches
1 decimeter = 3.937 in. = 0.328 ft.
1 meter = 39.37 in. = 1.0936 yards
1 dekameter = 1.9884 rods
1 kilometer = 0.62137 mile
1 inch = 2.54 centimeters
1 foot = 3.048 decimeters
1 rod = 0.5029 dekameter
1 yard = 0.9144 meter
1 mile = 1.6093 kilometers

Square Measure

1 sq. cm. = 0.1550 sq. in.
1 sq. decimeter = 0.1076 sq. ft.
1 sq. meter = 1.196 sq. yds.
1 hectare = 2.47 acres
1 sq. kilometer = 0.386 sq. miles
1 sq. in. = 6.452 sq. cm.
1 sq. foot = 9,2903 sq. decimeters
1 sq. yard = 0.8361 sq. meter
1 sq. mile = 2.59 sq. kilometers

Weights

1 dyne = .00102 grains
1 gram = 0.03527 ounces
1 kilogram = 2.2046 lbs.
1 metric ton = 2205 lbs.
1 pound = 0.4536 kilograms
1 metric ton = 1.1023 short tons
1 ounce = 28.35 grams = 437.5 grains

Alkalinity Equivalents

AMONG the mineral compounds present in natural waters, Calcium Carbonate is the most ubiquitous. Partly for this reason and partly because its molecular weight at the time, was thought to be exactly 100, this compound was chosen as the standard to be employed in the measurement of alkalinity and hardness.

With more accurate determination of atomic weights, the molecular weight of Calcium Carbonate is now assumed to be 100.08. Very obviously, tables earlier prepared under the assumption that the molecular weight was 100 will have a small and not entirely negligible error if the true weight be 100.08. The accompanying table, based upon the newer molecular weight of 100.08 for Calcium Carbonate, are arranged in such manner as to facilitate comparisons against other substances having different values of alkalinity. These values are presented as being more accurate than those appearing in earlier tables computed on the old 100 molecular weight value assumed for Calcium Carbonate.

A brief explanation of how the tables may be used follows.

In the sixth column, sixth line, the unity of Calcium Carbonate may be compared directly against every other factor in the column. For instance, one part of alkalinity, due to Calcium Carbonate, is the exact equivalent, in alkalinity value, to that which would be imparted by 1.6196 of Calcium Bicarbonate; 0.7403 of Calcium Hydroxide; 0.8424 of Magnesium Carbonate; 1.0590 of Sodium Carbonate (dehydrated), etc.

Along the line, right or left, a different comparison may be made. The molecular weight, for instance, of Calcium Bicarbonate, is in excess of that of Calcium Carbonate. Therefore, it takes more Calcium Bicarbonate to produce a given alkalinity than it does of Calcium Carbonate, and it is found that for an equal weight of Calcium Bicarbonate the alkalinity value as compared against Calcium Carbonate is only 0.6174 parts. On the other side an equal weight of Calcium Hydrate will have an alkalinity value of 1.3506 parts; Sodium Hydroxide 1.2508—and so on.

From the foregoing it is seen that the compounds in these tables may be compared in two different ways against the Calcium Carbonate Standard for alkalinity, or against any other compound in the table. For instance, under the heading Sodium Hydroxide (NaOH) it is noted that one part is equal in alkalinity value to 1.3247 parts of Sodium Carbonate (Soda Ash); and, further, that one part of Sodium Carbonate is only equal to 0.9442 parts of Calcium Carbonate in raising alkalinity values.

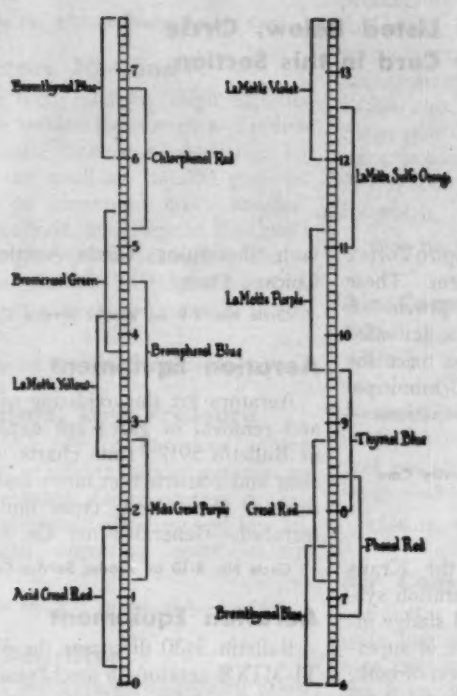
ALKALINITY EQUIVALENTS*

Compound	Formula	$Al_2(OH)_6$	BaO	$Ba(OH)_2$	CaO	$Ca(OH)_2$	$CaCO_3$	$CaH_2(CO_3)_2$	MgO	$Mg(OH)_2$
Aluminum Hydrate	$Al_2(OH)_6$	*1.0000*	0.3390	0.3034	0.9271	0.7017	0.5195	0.3207	1.2895	0.8913
Barium Oxide	BaO	2.9494	*1.0000*	0.8948	2.7734	2.0697	1.5323	0.9461	3.8035	2.6289
Barium Hydrate	$Ba(OH)_2$	3.2959	1.1174	*1.0000*	3.0559	2.3128	1.7123	1.0572	4.2503	2.9377
Calcium Oxide	CaO	1.0785	0.3656	0.3272	*1.0000*	0.7568	0.5603	0.3459	1.3908	0.9613
Calcium Hydrate	$Ca(OH)_2$	1.4250	0.4831	0.4323	1.3212	*1.0000*	0.7403	0.4571	1.8376	1.2701
Calcium Carbonate	$CaCO_3$	1.9247	0.6525	0.5839	1.7845	1.3506	*1.0000*	0.6174	2.4821	1.7155
Calcium BiCarbonate	$CaH_2(CO_3)_2$	3.1174	1.0569	0.9458	2.8904	2.1876	1.6196	*1.0000*	4.0202	2.7786
Magnesium Oxide	MgO	0.7754	0.2629	0.2352	0.7189	0.5441	0.4028	0.2487	*1.0000*	0.6911
Magnesium Hydrate	$Mg(OH)_2$	1.1219	0.3803	0.3403	1.0402	0.7873	0.5828	0.3598	1.4468	*1.0000*
Magnesium Carbonate	$MgCO_3$	1.6216	0.5498	0.4920	1.5035	1.1379	0.8425	0.5201	2.0912	1.4454
Magnesium BiCarbonate	$MgH_2(CO_3)_2$	2.8143	0.9541	0.8538	2.6094	1.9749	1.4621	0.9027	3.6293	2.5085
Sodium Oxide	Na_2O	1.1922	0.4042	0.3617	1.1054	0.8366	0.6194	0.3824	1.5375	1.0627
Sodium Hydrate	NaOH	1.5387	0.5217	0.4668	1.4267	1.0798	0.7994	0.4935	1.9843	1.3715
Sodium Carbonate	Na_2CO_3	2.0385	0.6911	0.6184	1.8900	1.4305	1.0590	0.6538	2.6288	1.8169
Sodium Carbonate, Hydrated	$NaCO_3,10H_2O$	5.5033	1.8658	1.6697	5.1025	3.8619	2.8592	1.7653	7.0969	4.9052
Sodium BiCarbonate	$NaHCO_3$	3.2312	1.0955	0.9803	2.9958	2.2674	1.6787	1.0364	4.1669	2.8800
*Tri-Sodium Phosphate	Na_3PO_4	2.1028	0.7129	0.6380	1.9497	1.4756	1.0925	0.6745	2.7118	1.8743
Tri-Sodium Phosphate, Hydrated	$Na_3PO_4,12H_2O$	4.8747	1.6527	1.4790	4.5197	3.4207	2.5326	1.5636	6.2863	4.3449

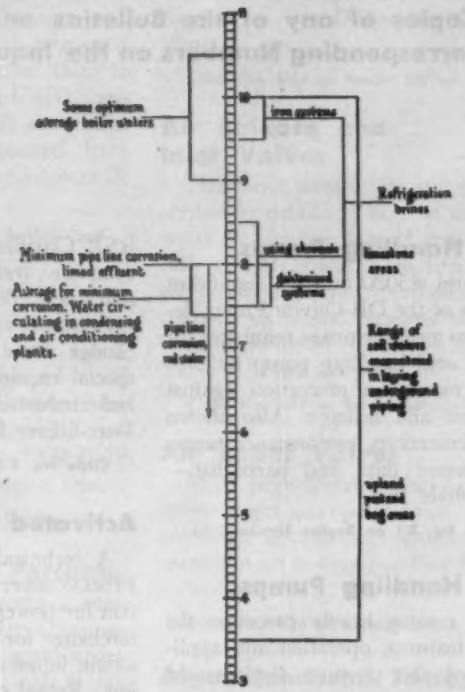
Compound	Formula	$MgCO_3$	$(CO_3)_2$	Na_2O	NaOH	Na_2CO_3	Na_2CO_3, $10H_2O$	$NaHCO_3$	Na_3PO_4	Na_3PO_4, $12H_2O$
Aluminum Hydrate	$Al_2(OH)_6$	0.6166	0.3553	0.8387	0.6498	0.4905	0.1817	0.3094	0.4755	0.2151
Barium Oxide	BaO	1.8187	1.0480	2.4737	1.9167	1.4468	0.5359	0.9128	1.4025	0.6050
Barium Hydrate	$Ba(OH)_2$	2.0324	1.1711	2.7643	2.1419	1.6168	0.5989	1.0200	1.5672	0.6761
Calcium Oxide	CaO	0.6650	0.3832	0.9046	0.7009	0.5290	0.1959	0.3337	0.5128	0.2212
Calcium Hydrate	$Ca(OH)_2$	0.8787	0.5063	1.1952	0.9260	0.6990	0.2589	0.4410	0.6776	0.2923
Calcium Carbonate	$CaCO_3$	1.1869	0.6839	1.6143	1.2508	0.9442	0.3497	0.5956	0.9152	0.3948
Calcium BiCarbonate	$CaH_2(CO_3)_2$	1.9223	1.1076	2.6146	2.0259	1.5292	0.5664	0.9647	1.4824	0.6395
Magnesium Oxide	MgO	0.4781	0.2755	0.6503	0.5039	0.3803	0.1409	0.2399	0.3687	0.1590
Magnesium Hydrate	$Mg(OH)_2$	0.6918	0.3986	0.9409	0.7291	0.5503	0.2038	0.3472	0.5334	0.2301
Magnesium Carbonate	$MgCO_3$	*1.0000*	0.5762	1.3601	1.0538	0.7955	0.2946	0.5018	0.7711	0.3326
Magnesium BiCarbonate	$MgH_2(CO_3)_2$	1.7354	*1.0000*	2.3604	1.8289	1.3806	0.5113	0.8709	1.3382	0.5773
Sodium Oxide	Na_2O	0.7352	0.4236	*1.0000*	0.7748	0.5848	0.2166	0.3689	0.5669	0.2445
Sodium Hydrate	NaOH	0.9488	0.5467	1.2906	*1.0000*	0.7548	0.2796	0.4762	0.7317	0.3156
Sodium Carbonate	Na_2CO_3	1.2570	0.7243	1.7097	1.3247	*1.0000*	0.3704	0.6308	0.9693	0.4181
Sodium Carbonate, Hydrated	$NaCO_3,10H_2O$	3.3936	1.9554	4.6157	3.5764	2.6996	*1.0000*	1.7031	2.6169	1.1289
Sodium BiCarbonate	$NaHCO_3$	1.9925	1.1481	2.7100	2.0998	1.3850	0.5871	*1.0000*	1.5364	0.6628
Tri-Sodium Phosphate	Na_3PO_4	1.2967	0.7471	1.7637	1.3665	1.0315	0.3821	0.6504	*1.0000*	0.4313
Tri-Sodium Phosphate, Hydrated	$Na_3PO_4,12H_2O$	3.0059	1.7320	4.0885	3.1679	2.3913	0.8857	1.5078	2.3181	*1.0000*

* Prepared by the late C. Arthur Brown, of Lorain, Ohio.

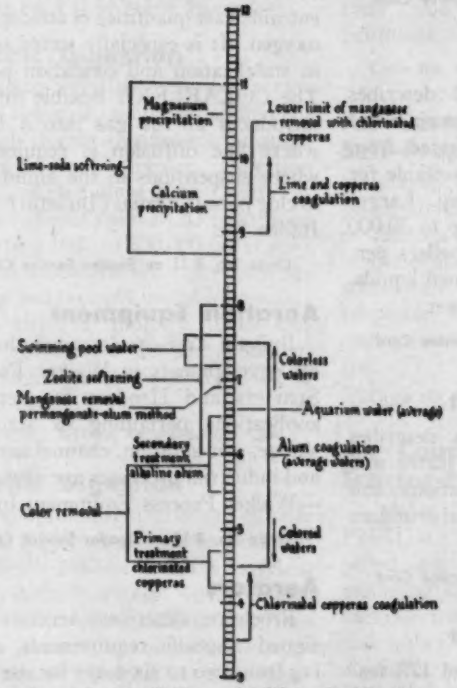
pH Zones in Water and Sewage Treatment*



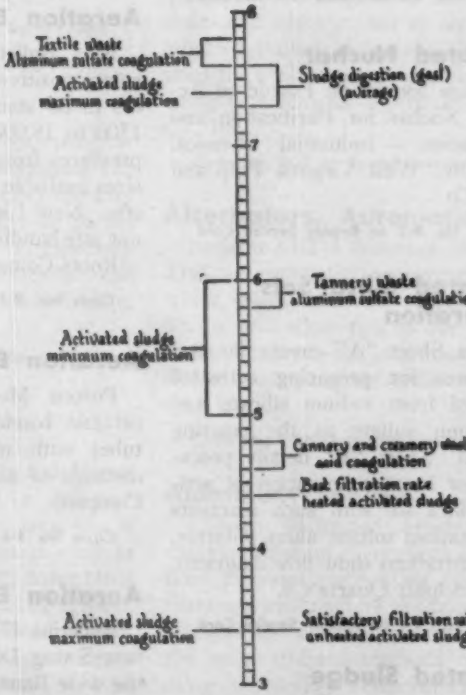
Ranges of Selected Indicators for PH Determination


Some optimum average boiler waters
iron systems
Refrigeration brines
Minimum pipe line corrosion, limed effluents
Average for minimum corrosion. Water circulating in condensing and air conditioning plants.
pipe line corrosion, soil water
limestone areas
Range of soil waters encountered in laying underground piping
upland natural bog areas

Approximate pH Zones Encountered in Common Corrosion Problems



Approximate pH Zones for Water Purification


Textile waste Aluminum sulfate coagulation
Activated sludge maximum coagulation
Sludge digestion (gas) (average)
Tannery waste aluminum sulfate coagulation
Activated sludge minimum coagulation
Cannery and creamery wastes acid coagulation
Best filtration rate heated activated sludge
Activated sludge maximum coagulation
Satisfactory filtration rate on heated activated sludge

Approximate pH Zones for Treatment of Sewages and Some Industrial Wastes

*Reproduced from the reference work "pH and Its Practical Application"—LaMotte, Kenny & Reed—(Williams and Wilkins, Publishers, Baltimore, Md.)

BULLETINS and CATALOGS

For Copies of any of the Bulletins or Catalogs Listed Below, Circle the Corresponding Numbers on the Inquiry Reply Card in this Section.

Acid Handling Pumps

Bulletin #5020 outlines significant features of the OB-Olivite Pump, designed to meet the prime requisites for a good acid handling pump by providing maximum protection against corrosion and leakage. Also shown are specifications, performance range, dimensioned data and parts list.—Dorr-Oliver Inc.

Circle No. R-1 on Reader Service Card

Acid Handling Pumps

This catalog briefly describes the design features, operation and application of this positive displacement metering pump for sulfuric acid in concentrations up to 60° Baumé.—Precision Chemical Pump Corp.

Circle No. R-2 on Reader Service Card

Activated Nuchar

12 page booklet on Powdered Activated Nuchar for Purification and Reclamation. — Industrial Chemical Sales Div., West Virginia Pulp and Paper Co.

Circle No. R-3 on Reader Service Card

Activated Silica Sols Preparation

Series Sheet "A" covers jar test procedures for preparing activated silica sol from sodium silicate and ammonium sulfate as the reacting chemical. Sheet "B" details procedures for batch preparation of activated silica sol with such reactants as ammonium sulfate, alum, chlorine, etc. Illustrations show flow diagrams. —Philadelphia Quartz Co.

Circle No. R-4 on Reader Service Card

Activated Sludge

Bulletin #7320 describes the D-O Aerator, the D-O Inka Aerator, the RSR Clarifier, and the SpiroVortex complete treatment system. These four new developments provide a variety of approaches to activated Sludge waste treatment to meet the special requirements of all municipal and industrial waste situations.—Dorr-Oliver Inc.

Circle No. R-5 on Reader Service Card

Activated Sludge

A technical study on the Kraus Process covers the dual aeration system for power savings and sludge interchange for beneficial use of supernatant liquor and elimination of bulking. Actual plant data. Design considerations.—Pacific Flush Tank Co.

Circle No. R-6 on Reader Service Card

Aeration Blowers

New Bulletin RAS-261 describes rotary positive displacement air blowers in 36 standard sizes rated from 1500 to 18,000 cfm, and suitable for pressures from 2 to 12 psig. Larger sizes available to handle up to 30,000 cfm. New Liqui-Pass impellers permit safe handling of entrained liquids. —Roots-Connersville Blower.

Circle No. R-7 on Reader Service Card

Aeration Equipment

Porous Media bulletin describes ceramic bonded diffuser plates and tubes with many applications and methods of use.—The Carborundum Company.

Circle No. R-8 on Reader Service Card

Aeration Equipment

Bulletins 175-A, 177 and 178 feature Swing Diffuser units utilized in the wide Band Aeration System with Precision Diffuser Tubes and in the Hydroshear Air Diffusion System with Shearfuser Nozzle Aerators.—Chicago Pump.

Circle No. R-9 on Reader Service Card

Aeration Equipment

Aerators for the oxidizing of iron and removal of gases are explained in Bulletin 5917. Data charts, materials and construction notes and pictures of the various types built are featured.—General Filter Co.

Circle No. R-10 on Reader Service Card

Aeration Equipment

Bulletin 5430 discusses the VORTI-MIX® aerator—a mechanical turbine type aerator used with a sparger. The VORTAIR® aerator (Bulletin 6620) is a turbine type aerator which entrains vast quantities of atmospheric oxygen. It is especially suited to use in stabilization and oxidation ponds. The COLAFLEX® flexible diffuser introduces air or gas into a liquid where fine diffusion is required or where suspensions in the liquid tend to clog porous media. (Bulletin 6550). Infilco Inc.

Circle No. R-11 on Reader Service Card

Aeration Equipment

Bulletin 22-S-96 describes the latest developments in Walker Process Sparjers and Headers for aeration applications pertaining to activated sludge, grit aeration, channel aeration and industrial processes are discussed. —Walker Process Equipment Inc.

Circle No. R-12 on Reader Service Card

Aerators

Brochure describes aerators designed to specific requirements, utilizing from two to six trays for use with or without coke. May be furnished drilled to sepcifications with removable fronts and/or removable trays. Trays may be fabricated as perma-

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nent installation or may be furnished removable.—Washington Aluminum Co., Inc.

Circle No. R-13 on Reader Service Card

Aerators Hi-Cone®

The high intensity, high capacity surface aerator for sewage and industrial waste treatment. Available for plants as small as 100,000 gpd—no limits on maximum flows handled. Bulletin 6661 describes the Hi-Cone's application to the activated sludge process; Bulletin 6650 for the aerobic digestion process.—Yeomans Brothers Co.

Circle No. R-14 on Reader Service Card

Aerators, Low Pressure

Bulletin #7318 describes a new method of efficient sludge aeration for the activated sludge process providing high power efficiency and low initial and operating costs.—Dorr-Oliver Inc.

Circle No. R-15 on Reader Service Card

Aer-Degritter

This brochure gives detailed information on the company's Aerated Grit Removal System.—Chicago Pump.

Circle No. R-16 on Reader Service Card

Aerobic Digestion

Bulletin SM-1010 describes a new line of low-cost, simplified equipment for high degree purification of small sewage flows. Aerobic Digestion plants, which achieve 85 to 95 per cent suspended solids and BOD reductions in treating 1000 to 200,000 GPD sewage and miscellaneous wastes, are becoming increasingly useful for institutions, airports, military bases and other enterprises remotely located from municipal sewer systems.—The Eimco Corp.

Circle No. R-17 on Reader Service Card

Aerobic Digestion

A simplified explanation of the aerobic digestion process is contained in Bulletin 1200 on Smith & Loveless factory-built "Oxigest" sewage treatment plants. The bulletin describes design features, operation and installation of the "Oxigest" sewage treatment plant, plus color photographs of representative installations.—Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-18 on Reader Service Card

Air Compressors

Bulletins LAH-158 and LAL-458 present Roots Spiraxial® compressors using internal compression with screw rotors. For 1 to 15 psig service, capacities range from 1100 to 12,250 cfm. New Model C-100 Two-Stage unit delivers 100 lb air. Seven sizes available with capacities from 900 to 3000 cfm.—Roots-Connersville Blower.

Circle No. R-19 on Reader Service Card

Air Compressors

Bulletins 124 and 989 describe White's Superior medium speed, heavy duty, balanced opposed Compressor. Built in 2, 4 and 6-cylinder models matched with Superior natural gas engines. 200 to 1000 BHP range.—White Diesel Engine Div.

Circle No. R-20 on Reader Service Card

Air Compressors, Portable

Bulletin SPB-58 presents a complete line of Portable Air Compressors, gasoline and diesel with capacities from 20 cfm to 600 cfm at 100 psi. Choice of skid, wheel or truck mounted models. Tool boxes, hose reels and other accessories.—Schramm, Inc.

Circle No. R-21 on Reader Service Card

Air Compressors, Self-Propelled

Catalog 5945 describes self-propelled air compressor furnishing 125 or 250 cfm at 100 psi. Easy mobility of these units plus ability to mount accessories makes them especially adaptable for both operational and maintenance applications.—Schramm, Inc.

Circle No. R-22 on Reader Service Card

Air Compressors, Tractor-type

Catalog 5740 presents the Heavy PNEUMATRACTOR, a self-propelled air compressor capable of mounting major accessories such as backhoe, front end loader, dozer blade and other construction equipment. Available with gas or diesel engine. Furnishes 125 cfm at 100 psi to operate accessories or separate tools.—Schramm, Inc.

Circle No. R-23 on Reader Service Card

Air Filter System

This brochure describes in detail the company's Super-Clean Air Filter System for Air Diffusion.—Chicago Pump.

Circle No. R-24 on Reader Service Card

Air Release and Inlet Valves

This much used utility valve is described in detail. It may be for both water and sewage lines. Used specifically at high points in the line where air collections must periodically be released or where vacuums must be broken. Bulletin 1205.—Simplex Valve & Meter Co.

Circle No. R-25 on Reader Service Card

Air Relief Valves

A 28 page booklet describing the construction and operation of Crispin automatic air valves available for the control of air in lines handling liquids.—Multiplex Mfg. Co.

Circle No. R-26 on Reader Service Card

Algae-Produced Tastes and Odors

8-page illustrated brochure describes Carox (T.M.) Potassium Permanganate technique for control of tastes and odors caused by algae and other vegetation, includes full instructions for evaluation of water for permanganate demand.—Carus Chemical Co., Inc.

Circle No. R-27 on Reader Service Card

Alternators, Automatic

Bulletin ALT-1 describes the Alto-Trol, an automatic sequence changer which, when used with suitable pilot device, will allow two to five pumps to be alternated one at a time at the end of each pumping cycle.—Healy-Ruff Co.

Circle No. R-28 on Reader Service Card

Aluminum Sulfate

32-page illustrated brochure on aluminum sulfate covers both applications in water purification (flocculation) and manufacture of the product, physical and chemical properties and the most efficient methods of handling and storing.—General Chemical Div., Allied Chemical Corp.

Circle No. R-29 on Reader Service Card

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Asbestos-Cement Pipe Accessories

Bulletin describes company's complete line of products designed for use with asbestos-cement pipe.—Smith-Blair, Inc.

Circle No. R-30 on Reader Service Card

Asbestos-Cement Pressure Pipe

4 page folder AP-17 describes advantages and features of asbestos-cement pressure pipe stressing the importance of "clear, full-flowing water —a community's most important asset."—Keasbey & Mattison Co.

Circle No. R-31 on Reader Service Card

Automatic Chlorine Residual Control

Catalog 40.189 describes Compound-loop Control for maintaining a consistent chlorine residual throughout a water treatment system. It shows equipment needed for automatic control. Also described is accessory equipment—remote recorders and controllers, chlorine flow recorders, and alarms.—Wallace & Tiernan Inc.

Circle No. R-32 on Reader Service Card

Automatic Continuous Weight Meter

Bulletins 375, 759, 851, and 858, fully describe and illustrate the Weightometer, an automatic continuous weighing scale that "Weighs as it conveys." It weighs and meters by mechanically multiplying together two variable quantities and totalizing the successive products.—Merrick Scale Mfg. Co.

Circle No. R-33 on Reader Service Card

Automatic Potential Control

Bulletin TP-118-E explains an improved system of cathodic protection, called Automatic Potential Control which extends previously possible applications of cathodic protection, and gives existing systems even greater economy, while providing full protection. The system is especially suitable for protection of submerged or buried structures. — Electro Rust-Proofing Corp.

Circle No. R-34 on Reader Service Card

Back Hoes

Literature available describes this manufacturers extensive line of Construction Equipment, including powerful P & H Hoes especially designed to dig trenches faster. Some of the advantages listed are: deep cuts, high lifts, big bites, fast work cycles and long trenching life with minimum maintenance.—Harnischfeger Corp.

Circle No. R-35 on Reader Service Card

Back Hoes, Shovels, Cranes, Draglines, etc.

Full series of feature and specification literature on complete Series 350 product line. Carrier-mounted, crawler-mounted and self-propelled models. Complete features and specifications on new Compact 250 backhoe, crane, shovel, clamshell, dragline.—Schield Bantam Co.

Circle No. R-36 on Reader Service Card

Ball Joint Cast Iron Pipe

For River Crossing and submarine piping. 8-page brochure gives description, specifications data, and assembly instructions for this pipe with 15 degrees full free turning deflection. —James B. Clow & Sons, Inc.

Circle No. R-37 on Reader Service Card

Barminutor

Bulletin 186-B illustrates and describes advantages, principals of operation, applications, mechanical descriptions, detailed specifications and other information on the company's Barminutor comminuting machines for use in rectangular channels.—Chicago Pump.

Circle No. R-38 on Reader Service Card

Bar Screens

REX Front Cleaned Bar Screens and their positive screenings removal are described in Bulletin 315-21.—Chain Belt Co.

Circle No. R-39 on Reader Service Card

Bar Screens, Sewage

This technical bulletin describes mechanically cleaned bar screen and grinder designed for a wide range of channel widths and settings with grinder attached to sorting tray, returning shredded screenings to sewage flow.—American Well Works.

Circle No. R-40 on Reader Service Card

Bascule Gate

This bulletin provides dimensions, description and typical installations of this crest gate for pond level and flood control.—Allis-Chalmers Mfg. Co.

Circle No. R-41 on Reader Service Card

Bell-Tite Joint Cast Iron Pipe

Bulletin describes this single gasket, compression type cast iron pipe joint for water and sewerage under pressure.—James B. Clow & Sons, Inc.

Circle No. R-42 on Reader Service Card

Blowers

Bulletins AF-258, RB-154, RAS-261 describe rotary positive displacement blowers which deliver air (or gas) free from oil vapors and other contaminants. Available in sizes from 5 to 30,000 cfm at pressures from 1 to 12 psig. Units can be operated in tandem for higher pressures.—Roots-Connersville Blower.

Circle No. R-43 on Reader Service Card

Blowers, Axial

Shows how units can provide profitable solution to wide range of air or gas handling problems. Available in size range of 8,000 to over 1,000,000 cfm. Axial characteristic curve shows basically constant volume with variable pressure output.—Allis-Chalmers Mfg. Co.

Circle No. R-44 on Reader Service Card

Boxes, Valve, Service, Roadway and Meter

Bulletins and Catalogs describing sizes and types of standard Buffalo and special types.—Opelika Foundry Co., Inc.

Circle No. R-45 on Reader Service Card

Car Shakers

Two bulletins describe features of 3½ and 5-ton car shakers for fast, safe, and economical pushbutton unloading of granular materials from open, hopper bottom gondola cars.—Allis-Chalmers Mfg. Co.

Circle No. R-46 on Reader Service Card

Cast Iron Pipe

Complete line of Cast Iron Pressure Pipe in sizes of 3 to 24 inches

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diameter is listed in catalog 54. Complete specifications and construction details.—Alabama Pipe Co.

Circle No. R-47 on Reader Service Card

Cast Iron Pipe

This illustrated booklet provides pictorial proof of the ruggedness and durability of cast iron pipe in water supply and distributions; sewer mains; and industrial service.—Cast Iron Pipe Research Assn.

Circle No. R-48 on Reader Service Card

Cathodic Protection

A series of three bulletins on cathodic protection: "Fighting Corrosion with Corrosion," "Cath-O-Chem System," and "Cathodic Protection for Water Works Plants." — Electro Rust-Proofing Corp.

Circle No. R-49 on Reader Service Card

Cathodic Protection

Technical Publication TP-118-E describes new cathodic protection system of Automatic Potential Control. Bulletin shows how automated system protects structures against corrosion at varying potentials when climatic or environmental conditions change. —Electro Rust-Proofing Corp.

Circle No. R-50 on Reader Service Card

Cement Mortar Linings for Pipes

A catalog describing the Centriline Process for pipes 4" to 144" including history and technical data on cement mortar linings, hydraulics of pipes and sample specifications for performing the work. — Centriline Corp.

Circle No. R-51 on Reader Service Card

Centrifugal Pumps

This 20-page bulletin describes monobloc, single and two stage, centrifugal pumps in sizes ¾ to 6 inches. Drawings and rating curves are also included.—Worthington Corp.

Circle No. R-52 on Reader Service Card

Ceramic Glazed Facing Tile

General Catalog S-61 gives many details and illustrations of the variable uses of Natco Ceramic Glazed Vitritile. This completely sanitary and low maintenance facing tile is suitable for all types of interior walls. —Natco Corp.

Circle No. R-53 on Reader Service Card

Chemical Feeders

4-page Bulletin 1400.20-1 describes this manufacturer's Treet-O-Control proportioneers, which offer a method of combining fluid meters and proportioning pumps so a given process will be continuous, with all units synchronized and controlled from a single source. — Builders-Providence Div., B-I-F Industries.

Circle No. R-54 on Reader Service Card

Chemical Feeders

Bulletin No. KSP-4 describes Komline-Sanderson chemical and slurry feed pumps, with their advantages and applications in the sewage treatment or water treatment plant. —Komline-Sanderson Eng. Corp.

Circle No. R-55 on Reader Service Card

Chemical Feeders

Catalog 390.010 discusses selection of dry feeders. Feeder selection table lists 175 commonly used dry, free-flowing solids with their densities and characteristics. Tabulated data and selection charts assure correct choice of appropriate feeder. Separate bulletins are available for each model of feeder.—Wallace & Tiernan Inc.

Circle No. R-56 on Reader Service Card

Chemicals for Pollution Control

File folder containing technical data and information on various special Pollution Control Chemicals, all formulated for the solution of specific problems encountered in sewage and industrial waste treatment and sewerage collection systems.—Division of Pollution Control Chemicals, Fine Organics, Inc.

Circle No. R-57 on Reader Service Card

Chemical Pumps

This catalog briefly describes the design features, operation and application of this positive displacement metering pump for chemical solutions. —Precision Chemical Pump Corp.

Circle No. R-58 on Reader Service Card

Chemical Services

Eight-page booklet describes in detail the chemical services offered by this manufacturer in areas of equipment, water and waste treatment and processing, laboratory and technical counseling, and product sales.—Dow Industrial Services Div., The Dow Chemical Co.

Circle No. R-59 on Reader Service Card

Chemonitor

Brochure describes instrument for continuous on-stream analysis of critical constitutents, such as silica, in water. Operates on colorimetric principle. In 0 to 300 parts per billion range can detect silica concentration as low as 5 ppb with a plus or minus 2 ppb accuracy.—Hagan Chemicals & Controls, Inc.

Circle No. R-60 on Reader Service Card

Chlorine

A bulletin describing the physical properties, handling methods, uses and containers.—Pennsalt Chemicals Corp., Pa.

Circle No. R-61 on Reader Service Card

Chlorine Dioxide

Catalogs 60.300 and 60.310 describe uses of chlorine dioxide in water and sewage treatment. Bulletins chart dosage, and show design and operation of Chlorine Dioxide Generator.—Wallace & Tiernan Inc.

Circle No. R-62 on Reader Service Card

Chlorine Evaporators

Specification Sheet 71V1000 describes electrically heated evaporators for automatic vaporization of chlorine or sulfur dioxide upon system demand. Sheet outlines operation, lists accessories and all specifications.—Fischer & Porter Co.

Circle No. R-63 on Reader Service Card

Chlorine Feeders

A series of bulletins on Chlorinizers, for feeding chlorine gas under vacuum, producing and delivering chlorine-water solution to the point of application. Bulletins 840.20-1, 840.20-2, 840.20-3 and 840.20-4.—Builders-Providence, Div., B-I-F Industries.

Circle No. R-64 on Reader Service Card

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Chlorine Feeders

Bulletin No. 100 describes the Advance Gas Chlorinator, a solution feed, vacuum operated gas chlorinator designed for the swimming pool industry. Available in 3 ranges: 50 to 5, 25 to 2.5, and 10 to 1 lbs. per 24 hours.—Capital Controls Co., Inc.

Circle No. R-65 on Reader Service Card

Chlorine Feeders

A series of catalogs on chlorinators and necessary equipment, ranging in application from swimming pools to high capacity industrial requirements. —Fischer & Porter Co.

Circle No. R-66 on Reader Service Card

Chlorine Feeders

Booklet TA-1041-C describes the complete range of V-notch Chlorinators. Individual bulletins are available for all models, suitable for any type of water and sewage treatment. —Wallace & Tiernan Inc.

Circle No. R-67 on Reader Service Card

Chlorine Hand Book

76 pages, hard cover, describes equipment for handling chlorine, including shipping containers, safety and first aid measures. Also covers preparation of lime and sodium bleaches and analytical data on hypochlorites. Bulletin No. 125.—Hooker Chemical Corp.

Circle No. R-68 on Reader Service Card

Chlorine Residual Control, Automatic

Six-page catalog 17B2200 describes the Anachlor Residual Chlorine Analyzer that automatically and continuously measures chlorine residuals and permits automatic control of the chlorination process. Folder outlines the Anachlor's operating principles, illustrates cell cabinet in detail, lists engineering data and specifications.—Fischer & Porter Co.

Circle No. R-69 on Reader Service Card

Chlorine—Safe Handling Practices

(No. C-4012). Bulletin outlines methods for employee protection, leak detection and handling, personal protective devices, emergency measures, first aid treatment.—Penn-salt Chemicals Corp., Industrial Chemicals (West).

Circle No. R-70 on Reader Service Card

Chlorine Wall Chart

This chlorine wall chart lists some of the important things to do in handling liquid chlorine in cylinders, ton containers and tank cars. It covers first aid and emergency procedures. The chart is clearly illustrated with diagrams of chlorine container valves. Bull. 132.—Hooker Chemical Corp.

Circle No. R-71 on Reader Service Card

Chlorine Wall Chart

Chart describes container valves, leak detection, first aid and accident procedures. — Pennsalt Chemicals Corp., Pa.

Circle No. R-72 on Reader Service Card

Clarifiers

Bulletin No. 4906 describes three types of circular clarifier mechanisms and gives selection data and dimensional data as well as specifications for all three types.—Ralph B. Carter Co.

Circle No. R-73 on Reader Service Card

Clarifiers

Bulletin 315-9A1 presents the REX Rim-Flo Clarifier design which employs a circular settling tank with flow being introduced at the periphery resulting in a lower inlet velocity than with center fed tanks. Bulletin 315-91 describes the REX Verti-Flo clarifier's outstanding feature of transforming the conventional horizontal flow tank into a vertical flow tank by a unique system of collecting troughs, weirs and partitioning baffles which divides the single, large horizontal settling zone into a series of small vertical-flow cells.—Chain Belt Co.

Circle No. R-74 on Reader Service Card

Clarifiers

Bulletin #6192 describes design features and advantages of Dorr mechanisms for circular and square settling basins. Photos and elevation drawings of units 30′ to 200′ in diameter are included in 16 pages.—Dorr-Oliver Inc.

Circle No. R-75 on Reader Service Card

Clarifiers

Eimco-Process Flotator-clarifier removes low specific gravity solids by a combination of dissolved air flotation and conventional sedimentation in a single tank. Bulletin SM-1008. —The Eimco Corp.

Circle No. R-76 on Reader Service Card

Clarifiers

In Bulletin 5811 the "Contraflo" clarifier and softener is described and illustrated. Flow charts and important features, essential to economical and efficient operation, are included. Typical industrial, utility and municipal Contraflo installations are shown and described.—General Filter Co.

Circle No. R-77 on Reader Service Card

Clarifiers

Bulletin #126, 32-pages with the theory, operating results, and necessary tables and charts required to design and specify the Lakeside Spiraflo Clarifier.—Lakeside Engineering Corp.

Circle No. R-78 on Reader Service Card

Clarifiers and Softeners

The ACCELATOR® high rate clarifier/softener incorporates the slurry recirculation principle in which treated water separates upwardly from a downward moving slurry mass. Thousands of such plants are in operation around the world. This plant is fully discussed in Bulletin 1825.—Infilco Inc.

Circle No. R-79 on Reader Service Card

Clarifiers, Center Drive

Type "CD" for tanks up to 50 ft in diameter and "CDH" for larger tanks are detailed in complete eight-page bulletin.—Yeomans Brothers Co.

Circle No. R-80 on Reader Service Card

Clarifiers, Rapid Sludge Return

Bulletin #6194 describes a design and operation of a recently developed clarifier designed specifically for the activated sludge plant. The special rake mechanism separates of treatable sludge from grit, and provides up-flow sludge removal for a high-

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rate return of the sludge to aeration. —Dorr-Oliver Inc.

Circle No. R-81 on Reader Service Card

Clariflocculator

Bulletin 6801-R describes the physical characteristics, principle of operation, types, sizes and advantages of this combination flocculation and clarification mechanism. Included are photographs of operating installations and line and wash drawings of standard units.—Dorr-Oliver Inc.

Circle No. R-82 on Reader Service Card

Clay Pipe

This 48-page fully illustrated brochure entitled "The Story of Clay Pipe" contains an historical record of clay pipe, its contribution to America from the beginning of the 20th century to the present, and a look into the future of American homes, industries, and communities. — National Clay Pipe Mfrs. Inc.

Circle No. R-83 on Reader Service Card

Clay Pipe

A 6-page brochure, "Lifetime Vitrified Clay Pipe," of particular interest to professional engineers. Lists of ASTM, ASA, and AASHO specifications applicable to vitrified clay pipe and describes new factory-made joints. Clay processing today, and the typical characteristics of vitrified clay pipe also are included.—National Clay Pipe Mfrs., Inc.

Circle No. R-84 on Reader Service Card

Clutches, Overland Release

"Modern Clutching for Water & Sewage Treatment Plants," is the title of 8-page Bulletin No. 305 discussing automatic drive control, of special interest to water and sewage executives and engineers. It offers complete coverage of the functions of Trig-O-Matic Overload Release Clutches in preventing costly damages from overloads.—Centric Clutch Co.

Circle No. R-85 on Reader Service Card

Coatings, Protective

A 4-page bulletin on Rexon coating No. 2 for protecting concrete pipe inside and out, from corrosive attack. —Hamilton Kent Mfg. Co.

Circle No. R-86 on Reader Service Card

Coatings, Protective

10-page brochure describes this manufacturer's painting systems for the preservation of steel water tanks. The 3 systems described are the Nocoro® Vinyl, the Nocoro Epoxy and the Nocoro Epoxy Primer with Vinyl top coats.—Industrial Paint Co.

Circle No. R-87 on Reader Service Card

Coagulant Aids

Carox (T.M.) Potassium Permanganate not only removes tastes and odors, iron and manganese, but offers the added benefit of serving as an efficient coagulant aid, as described in 8-page illustrated brochure, "Carox Potassium Permanganate for Quality Water."—Carus Chemical Co., Inc.

Circle No. R-88 on Reader Service Card

Coagulant Aids

Nomograph—"N-Sol" Process Coagulant aid preparation nomograph in chart form suitable for posting. Used to determine sodium silicate requirements, quantity of reacting chemical, necessary dilutions, expected alkalinity and preparations and feed rate for flow variations. All popular reacting chemicals listed. — Philadelphia Quartz Company.

Circle No. R-89 on Reader Service Card

Coagulants and Coagulant Aids

Seven Nalco products are described in informational bulletins. Information includes principal uses, shipping, handling, feeding information and a general description of each product.—Nalco Chemical Co.

Circle No. R-90 on Reader Service Card

Coagulant Disperser

Prints illustrate and describe the Nalco coagulant disperser, which thoroughly wets high polymer coagulants so they can be solubilized rapidly in solution tanks.—Nalco Chemical Co.

Circle No. R-91 on Reader Service Card

Coagulation

Process and product bulletins on coagulation are offered. The process bulletin details coagulation theory and practice. Product bulletins describe individual products listing principal uses, typical dosages and other specific data.—Nalco Chemical Co.

Circle No. R-92 on Reader Service Card

Coating Plastic

Literature describes this manufacturer's No Drip Plastic Coating, a product which can be used on metals, concrete, brick, tile or plaster surfaces. Applied by brush or spray to large pipes, tanks, walls, ceilings and air ducts, it eliminates sweating.—Mortell Co.

Circle No. R-93 on Reader Service Card

Combined Air Release and Vacuum Valves

Specially designed medium sized unit for both functions, these valves provide added safety and improve efficiency of pipe line installations. Described in Bulletin No. 1205.—Simplex Valve and Meter Co.

Circle No. R-94 on Reader Service Card

Combined Thickening and Clarification

Bulletin SM-1018 describes new Clari-Thickener sewage clarification are combined in a single treatment unit. Oxidative liquids are used to control septicity in Clari-Thickener operation. In many sewage treatment operations, Clari-Thickener treatment can eliminate need for separate thickening and clarification units. — The Eimco Corp.

Circle No. R-95 on Reader Service Card

Comminutors

Bulletin 184 describes the company's new 4" comminutor with two-way cutting designed for small sewage treatment plants and lift stations. Designed for flows of 15,000 gal. in eight hours to 30,000 gal. in 24 hours. —Chicago Pump.

Circle No. R-96 on Reader Service Card

Comminutors

Bulletin 185-D presents complete data, details and installation information on the company's large comminutors.—Chicago Pump.

Circle No. R-97 on Reader Service Card

Comminutors

Complete line of high-quality comminutors offered by Smith & Loveless are described in Bulletin 900. Engi-

neered to provide continuous, automatic screening and cutting of large sewage solids into small particles, without removing the solids from the sewage flow. Bulletin contains features of design and construction, selection data and recommendations for comminutor installations.—Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-98 on Reader Service Card

Compacting Mill

Literature describes compactor and equipment used to provide a low-cost, mechanical means for converting or upgrading particle size, for controlling product density and product solubility factors.—Allis-Chalmers Mfg. Co.

Circle No. R-99 on Reader Service Card

Concrete Forms

Literature describes this manufacturer's steel forms adaptable to a wide range of applications including the forming of concrete tanks and reservoirs, both circular and rectangular; foundations and walls; wall footings; bridges and bridge columns; culverts, etc.—Economy Forms Corp.

Circle No. R-100 on Reader Service Card

Concrete Forms

New 56-page Universal Catalog (1961 edition) now available. Forms, Form Ties, Accessories, Construction Specialties and Highway products are well illustrated and described.—Universal Form Clamp Co.

Circle No. R-101 on Reader Service Card

Concrete Forms, Brackets for

"How to Build a Form" is the title of a booklet offered by this manufacturer. The useful 12-page booklet combines a cartoon approach with actual in-plant photos in telling what it takes to make a form.—Symons Clamp & Mfg. Co.

Circle No. R-102 on Reader Service Card

Concrete Pressure Sewer Pipe

A folder discussing features and standards of concrete pressure sewer pipe.—Price Brothers Co.

Circle No. R-103 on Reader Service Card

Concrete Pressure Water Pipe

A 24-page booklet entitled "The Story of Concrete Pressure Pipe" explains and illustrates the principle of prestressing, and how prestressed pipe is manufactured. Also described are the procedures for installing and tapping pressure pipe, and facts about its principal uses. A complete table of sizes, weights and normal operating heads for each type of pipe used for water transmission and distribution lines, subaqueous intakes and outfalls, and sewage force mains is also included. Valuable information for engineers, contractors, and public officials.—Price Brothers Co.

Circle No. R-104 on Reader Service Card

Concrete Pressure Water Pipe Laying Manual

A booklet explaining and illustrating the proper method of laying concrete pressure pipe. The steps discussed are: digging the trench; checking grade; handling the pipe; lubricating joint rings; making the joint; checking the gasket; grade and line changes; completing the joint; bedding the pipe; and the use of pull jacks.—Price Brothers Co.

Circle No. R-105 on Reader Service Card

Concrete-Treating

Folder covers use of sodium silicate to make concrete harder, dustproof, acid-resistant and moisture-resistant. Cleaning concrete also detailed.—Philadelphia Quartz Company.

Circle No. R-106 on Reader Service Card

Construction Tools

Illustrated 4-page bulletin covers rock drills, paving breakers, diggers, spades and tampers with full variety of standard and specialized steels and other accessories.—Schramm, Inc.

Circle No. R-107 on Reader Service Card

Consulting Services

An extension to the managers or consultants staff when he needs it—is the approach taken by Nalco Chemical Company in a 16-page, illustrated brochure on its Consulting Services Department.—Nalco Chemical Co.

Circle No. R-108 on Reader Service Card

Continuous Belt Drum Filter

Bulletin F-2053 describes Eimco-Belt filter's unique operating principle which removes the belt filter medium from the drum continuously for cake discharge and cleaning. Wash sprays scour the filter medium front and back before it is returned to the drum, a function that effectively eliminates blinding of filter medium even dewatering difficult sewage sludges.—The Eimco Corp.

Circle No. R-109 on Reader Service Card

Controlled Closing Air Valve

Specifically designed to protect transmission lines against the dangerous effects of water hammer. Type CCAV valve contains unusual features of construction, which should be a part of every water transmission line and is described in bulletin 1225.—Simplex Valve & Meter Co.

Circle No. R-110 on Reader Service Card

Controllers

Describes SpaceMaker controller, first starter in the 2000-5000 volt range to use a two-high motor control center design. It is the first completely drawout control available in this voltage class and the lighter weight controller—about one-half that of previous design.—Allis-Chalmers Mfg. Co.

Circle No. R-111 on Reader Service Card

Controllers

Catalog C100-1B describes Tel-O-Set Miniature pneumatic instruments for measurement and control in water filtration plants.—Minneapolis-Honeywell Regulator Co.

Circle No. R-112 on Reader Service Card

Control Panels

New brochures describe various types of controls for integrating any vented tank system, pressure tank system or tankless system for water, waste or industrial processing and telemetering.—Autocon Industries, Inc.

Circle No. R-113 on Reader Service Card

Controls, Liquid Level

Bulletin No. KSM-6 describes electronic liquid level control, outlining

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features and giving specifications. Also describes the high level alarm available with this control.—Komline-Sanderson Eng. Corp.

Circle No. R-114 on Reader Service Card

Converters, Single to Three Phase

Bulletin 400 describes the company's entire line of motor phase conversion equipment, while Bulletins 123 and 305 more particularly describe the features of the patented Add-A-Phase converter with a special model specifically designed for sewer lift stations. — Add-A-Phase Div., System Analyzer Corp.

Circle No. R-115 on Reader Service Card

Copper Sulphate

Two booklets on the use of copper sulphate. "Copper sulphate in control of Microscopic Organisms," and "Copper sulphate for Root and Fungus Control in Sanitary Sewers and Storm Drains."—Phelps Dodge Refining Corp.

Circle No. R-116 on Reader Service Card

Copper Sulphate

A 13-page booklet describing the use and application of sulphate in water treatment and algae control, and containing charts of chemicals required for various treatments. — Tennessee Corp.

Circle No. R-117 on Reader Service Card

Corrosion Control

Process Bulletin C1 gives complete information about Nalco's complete line of corrosion inhibitors. Informative case histories document typical applications.—Nalco Chemical Co.

Circle No. R-118 on Reader Service Card

Curb Stops

Folder No. 400 gives complete information on the Nuseal® Curb Stop. Some of the exclusive features are: easy turning, since there is no contact between metal parts; bubble tight shut off and leak-proof service at 0 to 125 psi; flow may be in either direction; lifetime self lubrication and solid Tee head that indicates open and closed position.—Hayes Mfg. Co.

Circle No. R-119 on Reader Service Card

Cutters, Glass Tubing

Operating instructions available in convenient 4-page brochure. Cutter easily snaps off any length of gauge glass, laboratory tubing, and porcelain tubing up to ¾" diameter.—Wheeler Mfg. Corp.

Circle No. R-120 on Reader Service Card

Cutters, Pipe

Operating instructions and parts breakdowns are available for any of the Cutter Models in convenient 4-page brochures, with simple steps of operation clearly illustrated.—Wheeler Mfg. Corp.

Circle No. R-121 on Reader Service Card

Cutters—Pipe, Hydraulic, Pressure Pipe

Catalog sheet has chart of capacities of various pipe cutter models and photographs of each model. Cutters handle wide range of pipe sizes in cast iron, asbestos cement, terra cotta, corrosion-resistant and other relatively brittle pipe materials.—Wheeler Mfg. Corp.

Circle No. R-122 on Reader Service Card

Defoamant and Foam Control

Technical data sheet provides information on "Foamwilt," an effective all-weather defoamant. Desirable characteristics and test results from various sewage plants are given, along with physical properties.—Division of Pollution Control Chemicals, Fine Organics, Inc.

Circle No. R-123 on Reader Service Card

Degritting Clarifiers

This bulletin Number 6412, describes the design, operation and advantages of a new degritting device adaptable to both primary Clarifiers and Dorr Clarigester. Also included are installation photographs and sectional elevation drawings of typical grit handling facilities of this new design.—Dorr-Oliver Inc.

Circle No. R-124 on Reader Service Card

Densludge Digestion System

Bulletin 6262 describes the development, equipment, operation, typical applications and design loadings of this new sewage sludge digestion system and the means by which digestor capacity requirements are substantially reduced.—Dorr-Oliver Inc.

Circle No. R-125 on Reader Service Card

Desanding System

Literature describes and illustrates the Dorr-Clone desanding system for water supplies.—Dorr-Oliver Inc.

Circle No. R-126 on Reader Service Card

Diatomite Filters

Bulletin 1862.201-1 on diatomaceous earth filters for economical and efficient filtration of swimming pool and industrial process water.—Builders-Providence Div., B-I-F Industries.

Circle No. R-127 on Reader Service Card

Digester Circulator-Mixer

The Gaslifter digester sludge circulator promotes efficient digester performance. Programmed intermittent operation does not interfere with new sludge feed. Eliminates surface scum and bottom deposits.—Walker Process Equipment Inc.

Circle No. R-128 on Reader Service Card

Digestor Cover Roofing

A new concept in roofing for digester floating covers is described. in bulletin 333. This roofing is said to provide longer life with better insulation and minimum maintenance. —Pacific Flush Tank Co.

Circle No. R-129 on Reader Service Card

Digestion Equipment

Bulletin 145 describes in detail advantages, design, construction and operation information on the company's Catalytic Reduction Process for accelerated sludge digestion. — Chicago Pump.

Circle No. R-130 on Reader Service Card

Dispensing Meter, Coin Operated

Specification sheet describes a new dispensing meter for use where there is intermittent or sporadic water consumption. The unit features a 6-digit straight-reading totalizer. — Hersey-Sparling Meter Co.

Circle No. R-131 on Reader Service Card

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Distributors

"Water-Wheel" Rotary Distributor for trickling filter systems to maximum flows of 50,000 gpd. Complete specifications. — Yeomans Brothers Co.

Circle No. R-132 on Reader Service Card

Double Suction Split Case Pumps

4 page bulletin No. 1200 describes double suction, horizontally split case centrifugal pumps for long-life, low-cost municipal water pumping service.—The Weinman Pump Mfg. Co.

Circle No. R-133 on Reader Service Card

Drilling Machines

Folder describes the all new Mueller CL-12 Drilling Machine. Revolutionary feed control — completely automatic; boring bar cannot overtravel. Automatic or hand feed. Full vision indicator shows amount of travel at all times. Hand or power driven. Makes cuts from 2" to 12" in any size or kind of main.—Mueller Co.

Circle No. R-134 on Reader Service Card

Dry Feeders, Volumetric

Catalogs 320.120 and 320.130 describe two models of volumetric, screw-type, dry feeders for powdered or granular materials. Feeders are dust-proof, non-flooding, non-arching. Self-cleaning feed screw assures accurate delivery. Cat. No. 320.121 shows Series A-690 Feeder with Loss-of-Weight Recorder for permanent records of feeder operation.—Wallace & Tiernan, Inc.

Circle No. R-135 on Reader Service Card

Dry Feeders, Volumetric

Merchen Volumetric Feeder, vertical gate type, is described in Cat. 320.200. This belt-type feeder gives feed rates of 3 to 3000 lb./min. It accepts lumpy materials which screw-type feeders cannot handle. Optional off-feed switch. Convertible to gravimetric feeder by addition of weighing components. — Wallace & Tiernan, Inc.

Circle No. R-136 on Reader Service Card

Effluent Sampler

Bulletin describes the sampler and gives operating instructions.—Phipps & Bird, Inc.

Circle No. R-137 on Reader Service Card

Ejectors, Sewage

Bulletin No. KSM-2 describes unique features of Komline-Sanderson pneumatic sewage ejectors, gives plan and elevation drawings, with complete dimension and horsepower chart. Also provides complete specifications. Outlines air receiver dimensions and advantages of these ejectors.—Komline-Sanderson Eng. Corp.

Circle No. R-138 on Reader Service Card

Ejector Stations, Sewage

Bulletin No. KSM-3 on Komline-Sanderson Pneumatic Sewage Ejector Stations outlines construction features, furnishes compressor motor horsepower chart, plan and elevation line drawings of a typical station and specification chart. — Komline-Sanderson Eng. Corp.

Circle No. R-139 on Reader Service Card

Electrical Control Panels

This bulletin describes typical custom electrical control panels for sewage lift stations, water and sewage plants. — Smith & Loveless, Div. Union Tank Car Company.

Circle No. R-140 on Reader Service Card

Electric Motors

New booklet No. 502 on Low Speed Synchronous Motors, showing and telling about the performance, dependability and lasting economy of IDEAL Electric Motors, from 20 to 10,000 hp, and from 72 to 450 rpm.—The Ideal Electric and Mfg. Co.

Circle No. R-141 on Reader Service Card

Electric Motors

Large Vertical, 150 hp and larger. Bulletin 219 describes Ideal Hollow and Solid Shaft Squirrel Cage, synchronous and wound rotor motors. Bearing and coupling data, and sample specifications, along with complete cutaways of all units. — The Ideal Electric & Mfg. Co.

Circle No. R-142 on Reader Service Card

Electric Motors

High Speed Squirrel Cage Bulletin 210 illustrates and describes large high speed squirrel cage motors from 100 to 5000 hp, at speeds from 514 to 3600 rpm. Complete description of design and construction, with individual photos of sub-assemblies and the new simplified method of maintenance and servicing. — The Ideal Electric and Mfg. Co.

Circle No. R-143 on Reader Service Card

Electric Motors

This bulletin contains the line of U. S. Motors. Descriptions and full-color illustrations are included of open-type Uniclosed designs, totally-enclosed and explosion-proof types, Varidrives, Syncrogears, and right-angle worm gear models; also vertical motors and Verticlosed hollow-shaft types.—U. S. Electrical Motors, Inc.

Circle No. R-144 on Reader Service Card

Elevated Steel Tanks

A new 20-page brochure describing Horton spheroidal, ellipsoidal and radial-cone elevated steel tanks of welded construction. Illustrates a number of industrial and municipal tanks, describes dual service of tanks for general use and fire-protection. Lists table of standard capacities up to 3,000,000 gallons.—Chicago Bridge & Iron Co.

Circle No. R-145 on Reader Service Card

Elevated Water Tanks

A 16-page brochure describing the Watersphere and Waterspheroid. The modern structures are used in municipal and private water systems to provide gravity pressure for general service and fire protection, and this use is described in the booklet. A portion of the booklet illustrates the "skyline advertising" use of these structures.—Chicago Bridge & Iron Co.

Circle No. R-146 on Reader Service Card

Engines

A series of 4 bulletins describing Climax 4, 6, 8 and 12 cylinder gas engines in a range of sizes up to 600 hp. These engines are capable of operation on natural gas, butane, sewage gas, gasoline or a combination

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of any two of these fuels.—Climax Engine Mfg. Co., Div. of Waukesha Motor Co.

Circle No. R-147 on Reader Service Card

Engines

4-page bulletin, SA-631 describes Climax 6, 8 and 12 cylinder stationary gas engines for Municipal plant applications. These engines, from 180 to 600 hp, are capable of operation on natural gas, butane, sewage gas, gasoline or a combination of any two of these fuels.—Climax Engine Mfg. Co., Div. of Waukesha Motor Co.

Circle No. R-148 on Reader Service Card

Engines

Bulletin SA-612 describes the complete line of Climax engines from 100 to 600 hp. These engines, built in 6, 8 and 12 cylinder models are designed to operate on LP gas, gasoline, and sewage gas. — Climax Engine Mfg. Co., Div. of Waukesha Motor Co.

Circle No. R-149 on Reader Service Card

Engines

Bulletin E-9-A describes Roiline engines in 6 and 8 cylinder models from 1 to 400 hp. This 8-page bulletin points out the many features of the Roiline engines including application to Municipal plant operations.—Waukesha Motor Co.

Circle No. R-150 on Reader Service Card

Engines

Bulletin E-7-A describes the features of the Roiline V-12 engines designed to operate on LP gas, gasoline, or natural or sewage gas. The V-12 engines range in horsepower from 450 to 700 horsepower.—Waukesha Motor Co.

Circle No. R-151 on Reader Service Card

Engines

4-page bulletin GE-10 describes the complete line of Roiline engines. These engines designed for LP gas, natural gas, gasoline or sewage gas operation are built in 6, 8 and 12 cylinder models; in horespower range from 100 to 700 hp.—Waukesha Motor Co.

Circle No. R-152 on Reader Service Card

Engines

The complete line of Waukesha engines from 10 to 1235 horsepower are described in Bulletin 1079. Engines designed for operation on all fuels including diesel, gas, gasoline and natural gas are listed. Waukesha engines are built in 4, 6 and 12 cylinder models.—Waukesha Motor Co.

Circle No. R-153 on Reader Service Card

Engines

A series of 4 bulletins describing Roiline 6, 8 and 12 cylinders gas engines in a range of sizes up to 685 hp. These engines are capable of operation on natural gas, butane, sewage gas, gasoline or a combination of any two of these fuels.—Waukesha Motor Co.

Circle No. R-154 on Reader Service Card

Engines

Bulletins 108, 1081, 1082, 1083 describe White's Superior Model 40 Diesel, Dual Fuel or Gas Engines. Available 6 and 8 cylinders, naturally aspirated and supercharged, 215 to 1025 BHP, 150 to 725 KW generator sets.—White Diesel Engine Div.

Circle No. R-155 on Reader Service Card

Engines

Bulletin 1151 describes White's Superior diesel, dual-fuel and gas engines. Six basic engines, 26 models. 190 to 2150 BHP, 135 to 1500 KW engine-generator sets.—White Diesel Engine Div.

Circle No. R-156 on Reader Service Card

Engines

Bulletins 1101 and 111 describe White's Model 60, 65 and 80 Superior Stationary engines. Available in Diesel, dual-fuel and gas. Contains construction data, specifications, dimensions and performance curves.—White Diesel Engine Div.

Circle No. R-157 on Reader Service Card

Engines, Sewage Plant

A 20-page bulletin showing dual fuel engines, diesel engines and spark ignition engines. Contains engine selection chart, comparison fuel gas analysis chart and others.—Worthington Corp.

Circle No. R-158 on Reader Service Card

Engine-Generators

Bulletin 1837 describes the line of Waukesha built engine-generator sets and control panels. The "Enginators" are designed for all fuel operation and range in size from 50 to 750 KW. —Waukesha Motor Co.

Circle No. R-159 on Reader Service Card

Epoxy Mortar Linings for Pipes

A catalog describing the Centriline Process for applying acid resistant epoxy mortar to pipes 24" to 144". The process can be used to line single pipe lengths above ground, new pipe after it has been installed or recondition damaged steel, cast iron or concrete pipe.—Centriline Corp.

Circle No. R-160 on Reader Service Card

Equipment, Pneumatic

Bulletin M-200, a general catalog, describes the extensive line of Joy pneumatic equipment used by the contractor. It includes portable and stationary air compressors, rock drills, paving breakers, spaders, backfill tampers, sheeting drivers, air hose, air motors, etc.—Joy Mfg. Co.

Circle No. R-161 on Reader Service Card

Fastite Pipe for Liquid Service

Bulletin L126 describes AMERICAN Fastite® Joint pipe for water, sewage and other liquid service. Affords lower joint costs and time-saving advantages. Assembly methods are outlined and illustrated. Includes tables of working pressures and recommended deflections. Difficult installations are pictured.—American Cast Iron Pipe Company.

Circle No. R-162 on Reader Service Card

Feeding, Proportioning or Batching

The Feedoweight, a powered feed regulating machine, automatically feeds, blends, and proportions materials continuously by weight. Bulletins 158, 253, and 851 provide a complete explanatory text and are complete with numerous graphs, diagrams, and photographs. — Merrick Scale Mfg. Co.

Circle No. R-163 on Reader Service Card

Use Accompanying Reply Card to Obtain Copies of these Bulletins.

Fencing for Sewage Treatment Plants

Bulletin 1215 describes permanent, easy-to-install aluminum fencing for "Oxigest" sewage treatment plant installations. Fence is installed on special outriggers attached to the treatment plant. Eliminates settling of fence supports and provides attractive, rugged enclosure that complements surroundings.—Smith & Loveless, Div. Union Tank Car Co.

Circle No. R-164 on Reader Service Card

Ferri-Floc

A 38-page booklet describing the use and application of ferric sulphate in all phases of coagulation.—Tennessee Corp.

Circle No. R-165 on Reader Service Card

Fiberglass Specialties

This 8-page Bulletin contains complete engineering information on Wash Water Troughs, Parshall flume liners, weir plates, and various other fiberglass reinforced polyester resin products for use in water and sewage treatment plants.—F. B. Leopold Co., Inc.

Circle No. R-166 on Reader Service Card

Filters

General information on Roberts filters for municipal water purification industrial water rectification, swimming pool recirculating systems and pressure filters.—Roberts Filter Mfg. Co.

Circle No. R-167 on Reader Service Card

Filters, Automatic Backwash Sand

Bulletin No. 46-A gives construction details and specifications for a continuous rapid sand filter which cleans its own filter bed automatically on a time cycle or with predetermined increase in head pressure. The filter may be operated indefinitely without shutdown for backwashing. No "stand-by" unit is needed. Applications to industrial and municipal water treatment are discussed.—The Hardinge Co., Inc.

Circle No. R-168 on Reader Service Card

Filters, Diatomaceous Earth & Feedwater

Standard Filter is effective for removing suspended foreign matter from liquids. Refiner is designed for fine filtration and removal of both emulsified and free oil from condensate. Filter Catalog available.—Blackburn-Smith Mfg. Co.

Circle No. R-169 on Reader Service Card

Filters, Multicell

Horizontal, multicell filters are featured in bulletin 5624. Filter operation is explained and described in color flow diagrams. The bulletin also explains the "Multiplate" baffle under-drain system.—General Filter Co.

Circle No. R-170 on Reader Service Card

Filter Fly Control

This is a descriptive brochure on Formula R.S.C. insecticide with instructions on how to use it for control of Psychoda flies, both in trickling filter beds and on surrounding premises. Formula R.S.C. contains an inhibitory factor which prevents Psychoda from developing a resistance to it. Bulletin R-626.—Glenn Chemical Company.

Circle No. R-171 on Reader Service Card

Filter Media

18-page technical bulletin describes in detail the characteristics and advantages of this manufacturer's hard-coal filter medium marketed under the trade name of "Anthrafilt," used in place of sand and gravel in all kinds of filters.—Anthracite Equipment Corp.

Circle No. R-172 on Reader Service Card

Filter Media

New Eimco bulletin on F-2037A synthetic fabric filter media describes the wide range of media available today for vacuum and pressure filters and points out the important role of proper filter media selection in getting best results in filtration.—The Eimco Corp.

Circle No. R-173 on Reader Service Card

Filter Plants

Filter plants for the removal of iron, manganese, taste, odor, and gas are described in a new General Filter bulletin. Various problems are listed and answers given. Four basic treatment methods are described and graphically shown in drawings. Actual installations in all parts of the country are shown.—General Filter Co.

Circle No. R-174 on Reader Service Card

Filter Underdrains

Porous Media bulletin describes ceramic bonded plates for use in water filters, softeners, etc., eliminating graded gravel support for filter media.—The Carborundum Company.

Circle No. R-175 on Reader Service Card

Filter Underdrains

4-page Bulletin fully describes the Compound Duplex, vitrified, de-aired, salt glazed tile underdrain system for rapid sand filters. This bulletin contains installation drawings, detail engineering information, as well as typical specifications of material.—F. B. Leopold Co., Inc.

Circle No. R-176 on Reader Service Card

Filter Underdrains

Shape bulletins TF-5 and TF-8 contain useful information on Natco salt glazed Tri-Filter Blocks, which are available for both standard and high rate trickling filter systems.—Natco Corp.

Circle No. R-177 on Reader Service Card

Filtration

New, definitive brochure on diatomite filtration of water. Covers broad aspects as well as technical details of diatomite filtration principles, various filter systems available, and their operation.—Johns-Manville.

Circle No. R-178 on Reader Service Card

Financing Water and Sewage Works

This booklet is designed planning and financing water and sewage works. It points out the need for sanitation facilities and stresses the revenue bond method of financing. Also discussed are factors to be considered in a determination of fair rate schedules for water and sewage charges.—Portland Cement Association.

Circle No. R-179 on Reader Service Card

Use Accompanying Reply Card to Obtain Copies of these Bulletins.

Fire Hydrants

44 page bulletin No. 5710 gives complete information on the Darling B-50-B Fire Hydrants with Ball Bearings for ease of operation and "O" Rings instead of the usual stuffing box.—Darling Valve & Mfg. Co.

Circle No. R-180 on Reader Service Card

Fire Hydrants

This 18-page catalog illustrates and describes the Ludlow slide gate type of hydrant. — Ludlow Valve Manufacturing Co., Inc.

Circle No. R-181 on Reader Service Card

Fire Hydrants

Twelve page circular describing standard, traffic and flush models of fire hydrants, how to install, lengthen and repair, and special features. Circular No. 22—M & H Valve and Fittings Co.

Circle No. R-182 on Reader Service Card

Fire Hydrants

A 20-page catalog H53 showing a complete line of AWWA approved hydrants together with detailed illustrations of construction, mechanical drawings, bills of materials, approved construction, installation and inspection data.—A. P. Smith Manufacturing Co.

Circle No. R-183 on Reader Service Card

Fire Hydrants

Literature illustrating and describing the R. D. Wood-"Mathews" Modernized and "Mathews" Flanged Barrel fire hydrants, the latter in both the standard and breakflange designs, conforming to latest AWWA specifications, and with conventional stuffing box or "O"-ring pressure seal. Also lists gate valves.—R. D. Wood Co.

Circle No. R-184 on Reader Service Card

Fire Hydrants & Gate Valves

Compact brochure describes all the features of Mueller AWWA Improved Fire Hydrants and AWWA Gate Valves. Many other illustrations show the types of hydrants available, and the more popular end combinations to be had in gate valves, whether with "O" Ring seals or conventional packing.—Mueller Co.

Circle No. R-185 on Reader Service Card

Fire Hydrants, Gate Valves, Tapping Machines, etc.

A 12-page condensed catalog M58, available in either Spanish or English edition, showing Smith line of products. Hydrants, gate valves, tapping machines, sleeves, tapping valves, cut-in sleeve & valve, inserting machines & valves, check valves and repair sleeves.—A. P. Smith Manufacturing Co.

Circle No. R-186 on Reader Service Card

Fire-Hydrants, Ring-Tite

Bulletin RT-53 illustrates and describes the line of fire hydrants and gate valves with Ringtite connecting joints made by the company.—A. P. Smith Mfg. Co.

Circle No. R-187 on Reader Service Card

Fire Pumps

Literature tells of fire and low-pressure (booster) pumps approved by Underwriters Laboratories, Inc., or Associated Factory Mutual Fire Insurance Companies for heads from 50 to 145 psi and capacities from 500 to 2500 gals. per minute.—Allis-Chalmers Mfg. Co.

Circle No. R-188 on Reader Service Card

Flexible Joint Cast Iron Pipe, Boltless

Usiflex® flexible joint pipe for submarine installations where substantial deflection is needed. 8-page booklet describes joint and its assembly; table shows dimensions and weights.—U. S. Pipe & Foundry Co.

Circle No. R-189 on Reader Service Card

Flocculators

Bulletin No. 6971 contains a description of Dorr-Oliver equipment used to perform the two basic steps of flash mixing and flocculation.—Dorr-Oliver, Inc.

Circle No. R-190 on Reader Service Card

Flocculation Equipment

This bulletin covers the pretreatment of water. Bulletin 315-51 presents the design and benefits of REX Floctrol equipment, REX Slo-Mixers and REX Flash-Mixers. — Chain Belt Co.

Circle No. R-191 on Reader Service Card

Flocculation Equipment

An 8-page booklet, "Equipment for Chemical Flocculation" illustrates and discusses Link-Belt's line of conveyors and elevators for handling chemicals and flash and straightline mixers.—Link-Belt Co.

Circle No. R-192 on Reader Service Card

Flocculation Units

Bulletin AH-484. A single sheet showing construction details of the Hardinge Flocculation Units which proceed settling tanks in applications where controlled conditioning of the water is necessary before clarification or filtration, or both.—The Hardinge Co., Inc.

Circle No. R-193 on Reader Service Card

Floating Covers

Bulletin No. 1008 describes design and application of digester covers, gas holders and pre-fabricated roofing.—Ralph B. Carter Co.

Circle No. R-194 on Reader Service Card

Floating Covers

This brochure gives design and application data on positive, non-tipping construction of "Chicago" Pontoon Digester Floating Covers.—Chicago Pump.

Circle No. R-195 on Reader Service Card

Floating Covers

A bulletin that covers in 40 pages the theory of control digestion with digester design considerations, digester operation and floating cover construction details.—Pacific Flush Tank Co.

Circle No. R-196 on Reader Service Card

Float in Flume

Bulletin 726 describes the float in flume used with Type "S" Parabolic Flume. A modern concept of measuring gravity flow through time proven Simplex parabolic flume. Accurate flow measurement is transmitted either electrically or pneumatically to remotely located indicating, recording or totalizing receivers. Eliminates costly stilling well

and simplifies maintenance problems. —Simplex Valve and Meter Co.

Circle No. R-197 on Reader Service Card

Float in Flume

Bulletin 727 describes Simplex Float in Flume adapted for use with standard Parshall flume. Transmitter is designed for different maximum capacities for each flume size. Linear transmission of flow data, either pneumatically or electrically to remotely located indicating, recording and totalizing receiver. — Simplex Valve & Meter Co.

Circle No. R-198 on Reader Service Card

Flotation Unit, Gibbs

Bulletin No. KSG describes and shows various applications of the Gibbs Flotation Unit.—Komline-Sanderson Eng. Corp.

Circle No. R-199 on Reader Service Card

Flow Measurement

Bulletins 100.20-1 and 110.20-2 describe ten Differential Producers, including Dall Flow Tubes, Herschel Standard Venturi Tubes, Venturi Flow Nozzles and the Plastic Parshall Flume Liner.—Builders-Providence Div., B-I-F Industries.

Circle No. R-200 on Reader Service Card

Fluo-Chlorinator

Specification Sheet 70F1410 describes this vacuum type chlorinator designed to feed chlorine gas at a controlled rate in solution with a fluoride solution. Sheet lists chlorine flowmeter range and water requirements. Also lists specifications and outlines operation.—Fischer & Porter Co.

Circle No. R-201 on Reader Service Card

Fluoridators

Wall-mounted solution dispenser, designed to mix and feed a fluoride solution smoothly, is described in Specification Sheet 70D1100. Sheet also lists engineering data and illustrates and describes operation of the equipment.—Fischer & Porter Co.

Circle No. R-202 on Reader Service Card

Fluoridators

Bulletin TP-69-M describes a Volumetric Fluoridator. An accurate and dependable dry feeder, the Series A-378 is ideal for water supplies up to 7 million gallons a day.—Wallace & Tiernan, Inc.

Circle No. R-203 on Reader Service Card

Fluoride Feeders

Bulletin 23-02.20-2 describes methods and equipment for accurate, continuous volumetric feeding of fluoride compounds to a water treatment system.—Builders-Providence Div., B-I-F Industries.

Circle No. R-204 on Reader Service Card

Gas Pumps, Rotary Positive

Bulletin RAS-261 presents Roots rotary positive gas pumps which feature vertical arrangement of impellers to provide horizontal inlet and discharge connections. New Liqui-Pass impellers with special contour can handle moderate amounts of entrained liquid without damage. Capacities to 30,000 cfm, pressures to 12 psig.—Roots-Connersville Blower.

Circle No. R-205 on Reader Service Card

Gas Safety Equipment

This bulletin provides capacity curves along with detailed drawings of a complete line of gas safety equipment designed expressly for sewage sludge gas. The bulletin also pictures a number of typical installations and provides a standard layout of a digester gas piping system. — Pacific Flush Tank Co.

Circle No. R-206 on Reader Service Card

Gate Valves

A 64-page catalog V56 showing a complete line of AWWA approved valves with all types of controls, mechanical drawings, bills of materials, optional construction, and technical data.—A. P. Smith Manufacturing Co.

Circle No. R-207 on Reader Service Card

Gate Valve, Bonnetless

Literature describes fabricated bonnetless gate valve, designed for handling fibrous, viscous and slurry type flows.—De Zurik Corp.

Circle No. R-208 on Reader Service Card

Gear Cutting, Grinding, Machining

Jobbing brochure explains services offered by this company in gear manufacturing and machine work conforming to the exacting standards of the American Gear Manufacturers' Association.—Johnson Gear & Mfg. Co., Ltd.

Circle No. R-209 on Reader Service Card

Gear Drive, Right Angle

Catalog No. 32 describes Johnson Right Angle Gear Drives which provide economical, efficient and positive power transmission from horizontal prime movers to vertical pump shafts. Applications include cooling tower installations, sewage disposal, fire and flood protection, and many others.—Johnson Gear & Mfg. Co., Ltd.

Circle No. R-210 on Reader Service Card

Generator Sets

Series of bulletins describe White's Superior Engine Generator Sets for prime, supplementary and standby power, 135 to 1500 KW. Automatic and remote control operation.—White Diesel Engine Div.

Circle No. R-211 on Reader Service Card

Glazed and Unglazed Face Brick

Light construction Catalog SB-61 describes and illustrates the wide range of Natco Standard, Roman, Norman, Jumbo and SCR Face Brick.—Natco Corp.

Circle No. R-212 on Reader Service Card

Gratings

Booklet discusses in detail the construction, design and load capacity of corrosion resistant aluminum gratings. Also contains information on aluminum stair and ladder treads.—Washington Aluminum Co.

Circle No. R-213 on Reader Service Card

Gravity Sewer Pipe

New crushing strengths, 4 page folder AP-19 describes five engineering classifications of K&M asbestos-cement gravity sewer pipe. Intended as an aid to engineers to help them meet more exactly the requirements of soil conditions, as well as depth of

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trench, width of trench, manner of bedding. Crushing strengths, sizes and a crushing table based on the Marston formula are presented.—Keasbey & Mattison Co.

Circle No. R-214 on Reader Service Card

Grease & Sludge Deposit Solvent

Technical bulletin describes "Greasewilt," a safe to handle, non-caustic, non-corrosive concentrate, with high-solvent power surface active agents, for safe, fast removal of heavy grease deposits in sewer and sludge draining lines, in force mains, lift station wet wells, wherever grease accumulations present a problem.—Division of Pollution Control Chemicals, Fine Organics, Inc.

Circle No. R-215 on Reader Service Card

Grit Collecting Washing Equipment

Book 2571 is the latest publication presently being distributed. The 28-page book is profusely illustrated, tab indexed, and three-hole punched for permanent retention in the Link-Belt Sanitary Engineering Binder.—Link-Belt Company.

Circle No. R-216 on Reader Service Card

Grit Collectors

REX Grit Collectors with the recirculation feature for satisfactory conditioning completely mechanized and incorporating proportional weirs for velocity control are described in Bulletin 315-41.—Chain Belt Co.

Circle No. R-217 on Reader Service Card

Grit Separators

Eimco-Process separators are built in five separate types, to handle any specialized application need. Valuable speed drives for varying flows. Bulletin SM-1007.—The Eimco Corp.

Circle No. R-218 on Reader Service Card

Gunite

This 48-page booklet illustrates Gunite for repair and restoration to all existing concrete and masonry structures. Typical specifications are listed.—Pressure Concrete Co.

Circle No. R-219 on Reader Service Card

Heat Exchangers

Bulletin 6281 on the spiral heat exchanger, an external element of the spiral flow type for controlling digestion tank temperatures.—Dorr-Oliver, Inc.

Circle No. R-220 on Reader Service Card

Heat Exchangers

A 28-page bulletin presents a concise explanation of effective digester heating, scum control and operation of the P. F. T. Sludge Heater. Bulletin includes a method of computing size of heater and heat exchangers and table with complete size and operating data.—Pacific Flush Tank Co.

Circle No. R-221 on Reader Service Card

Horizontal Compressors

This 24-page bulletin discusses single stage, 10-150 psi, 5-2000 cfm compressors. It also contains drawings and specifications. — Worthington Corp.

Circle No. R-222 on Reader Service Card

Hydra-Pneumatic Controls

Literature describes the new Flow-Trol Hydra-Pneumatic system for combination air-water valve control. —F. B. Leopold Co., Inc.

Circle No. R-223 on Reader Service Card

Hydrofluosilicic Acids

A brochure on Hydrofluosilicic acid and its uses for fluoridation by municipalities.—International Minerals & Chemical Corp.

Circle No. R-224 on Reader Service Card

Hydrogen Sulfide Removal

8-page illustrated brochure describes Carox (T.M.) Potassium Permanganate technique for hydrogen sulfide removal; includes full instructions for evaluation of water for permanganated demand. — Carus Chemical Co., Inc.

Circle No. R-225 on Reader Service Card

Hydrogen Zeolite Softener

Provides general description of unit for control of hardness, alkalinity, total dissolved solids, and corrosive CO_2. — Allis Chalmers Mfg. Co.

Circle No. R-226 on Reader Service Card

Hypochlorinators

Bulletin 1910-02.20-1 describes the Chem-O-Feeder, an air-operated diaphragm type chemical solution feeder designed to control feeding of Hypochlorite and other water treatment chemical solutions into small water systems usually having a capacity of not over 25 gpm.—Builders-Providence Div., B-I-F Industries.

Circle No. R-227 on Reader Service Card

Hypochlorinators

Catalog 80.130 describes Series A-747 Hypochlorinator (maximum capacity—250 gallons per day) which is suitable for all chemical solutions used in water and sewage treatment. Series A-748, described in Catalog 80.140, has dual heads, pumps twice the quantity, against up to 100 psi. Feed rates of both models are adjustable over a 10-1 range while the pump is operating.—Wallace & Tiernan, Inc.

Circle No. R-228 on Reader Service Card

Incinerator Stoker

Bulletin IS-1 gives complete information about the "continuous process" design and applications of the C-E Incinerator Stoker. — Combustion Engineering, Inc.

Circle No. R-229 on Reader Service Card

Indicators, Sight Flow

Bulletin F-6 describes how Visi-Flo Sight Flow Indicators "put a window in your pipeline." Lets you know what is happening at all times: flow, purity, viscosity, etc.—OPW-Jordan Corporation.

Circle No. R-230 on Reader Service Card

Industrial Waste Treatment

Bulletin 315-111, "Industrial Waste Treatment," presents the complete line of REX equipment available to recover valuable materials; to clarify process water or liquids for re-use; to eliminate pollution and annoyance.—Chain Belt Co.

Circle No. R-231 on Reader Service Card

Industrial Waste Treatment

66 page catalog outlines entire line of equipment for industrial waste treatment.—Jeffrey Mfg. Co.

Circle No. R-232 on Reader Service Card

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Instrument Accessories

60 page catalog containing specifications, part numbers and prices on the more than 250 commonly furnished Foxboro instrument parts and supplies.—Foxboro Co.

Circle No. R-233 on Reader Service Card

Instrumentation

Data sheets for instrumentation on water and sewage treatment plants; the different types of equipment used and their application. — Fischer & Porter Co.

Circle No. R-234 on Reader Service Card

Instrumentation

A 16-page booklet covering Foxboro instruments manufactured for water and sewage works applications. —Foxboro Co.

Circle No. R-235 on Reader Service Card

Instrumentation

Bulletin B96-2 on Industrial Water Treatment, and its companion Bulletin B97-1 on Treatment of Water and Sewage, show you how specific companies use instruments for closer control, increased efficiency, and better operating economy. The bulletins, together, show you the wide range of applications possible for instrumentation and control in the water and sewage treatment field. —Minneapolis-Honeywell Regulator Co.

Circle No. R-236 on Reader Service Card

Ion Exchange

Bulletin Z-5 (2nd edition) is a 60-page handbook for men who are responsible for water supplies. Included within is basic data on ways of conditioning water with Nalcite Ion Exchangers and straightforward explanations on how you can figure costs and results using the various methods.—Nalco Chemical Co.

Circle No. R-237 on Reader Service Card

Iron Removal

Published case history reports describe actual water department experiences using potassium permanganate for iron and manganese removal. —Carus Chemical Co., Inc.

Circle No. R-238 on Reader Service Card

Iron Removal

8-page illustrated brochure describes Carox (T.M.) Potassium Permanganate technique for iron removal, includes full instructions for evaluation of water for permanganate demand.—Carus Chemical Co., Inc.

Circle No. R-239 on Reader Service Card

Jacks and Pullers

Both SIMPLEX Mechanical and Hydraulic Jacks are concisely presented in Bulletin Industrial-61. Drop-forged Steel Trench Braces and Timber Braces are also described.—Templeton, Kenly & Co.

Circle No. R-240 on Reader Service Card

Jacks and Pullers, Hydraulic

81 SIMPLEX Hydraulic models to choose from are illustrated and described in Hydraulic Catalog No. 60. They consist of standard type; "Jenny" center-hole Hydraulic Pullers; Hydra-lift, foot lift Hydraulic Jacks; Re-Mo-Trol Pullers and Rams; Hydraulic Service and Bumper Jacks; Hydraulic Two and Three Grip Pullers; and, Hand and Powered Pumps. — Templeton, Kenly & Co.

Circle No. R-241 on Reader Service Card

Jacks, Mechanical

45 SIMPLEX Lever, and 146 SIMPLEX Screw Jacks are illustrated and described in Mechanical Catalog No. 60.—Templeton, Kenly & Co.

Circle No. R-242 on Reader Service Card

Joint Cut-In-Valves

Specifications, installation illustrations and explanatory text are included in this bulletin on mechanical joint cut-in valves and sleeves.—A. P. Smith Mfg. Co.

Circle No. R-243 on Reader Service Card

Joints, Rubber

20 page booklet describing Tylox rubber gaskets for leakproof coupling of concrete and vitrified clay sewer pipe.—Hamilton Kent Mfg. Co.

Circle No. R-244 on Reader Service Card

Joints, Slip

Brochure on Crispin slip joints describing safe, fast way to remove and replace fixtures when repairing lines, etc.—Multiplex Mfg. Co.

Circle No. R-245 on Reader Service Card

Landscaping Equipment

Literature available illustrates and describes this manufacturer's line of landscaping equipment. The Ryan Sod Cutters strip and save sod for drainfields, sewer lines, water lines. The Ryan Rollaire compacts and levels the soil and eliminates air pockets under re-laid sod, assuring firm sod-to-soil contact.—Ryan Landscaping Equipment Co.

Circle No. R-246 on Reader Service Card

Large Dial Gauges

Where large dial gauges are still required for filter plant operation, it will be of interest to the designing engineer to have details and dimensions for this type of gauge. While this form of gauge may be mechanically or electrically operated, pneumatic operations also available. Described in bulletin 1002. — Simplex Valve & Meter Co.

Circle No. R-247 on Reader Service Card

Lift Stations

Bulletin No. 121 describes in detail the company's UT Packaged Underground Lift Station with Flush-Kleen Sewage pumps. — Chicago Pump.

Circle No. R-248 on Reader Service Card

Lift Stations

Manufactured underground sewage lift stations equipped with centrifugal pumps or pneumatic ejectors are detailed in separate catalogs.—Yeomans Brothers Co.

Circle No. R-249 on Reader Service Card

Lime Slakers

Catalog 330.100 describes the Series A-758 Lime Slaker, available in four models, 1-, 2-, 4-, and 8,000 lb./hr. Each model proportions water and quicklime automatically, slakes lime continuously as a paste. Slaking time is reduced to 5 mins., water to lime ratio only 2:1. External hot water and heat exchanger equipment are eliminated. Automatic grit removal. — Wallace & Tiernan, Inc.

Circle No. R-250 on Reader Service Card

Use Accompanying Reply Card to Obtain Copies of these Bulletins.

Liquid Chemical Feeders

Bulletins describe various liquid chemical feeders (diaphragm pumps) available for a wide range of uses. Feeders are versatile, economical, and resistant to corrosion. Catalog No. 80.120 shows the Chlorinet® model, designed for small water systems such as farms, camps, motels, swimming pools, etc. — Wallace & Tiernan, Inc.

Circle No. R-251 on Reader Service Card

Liquid Level Alarm

Literature describes Kenco's improved Model 108C Liquid Level Alarm. Serving as a normally-open switch, it goes into action as the level of the water or liquid rises, causing air to be trapped in the unit's skirt and exerting pressure on its sensitive diaphragm that actuates the fully enclosed, protected switch.—Kenco Pump Division.

Circle No. R-252 on Reader Service Card

Low Pressure Meter

Literature describes a propellor type low pressure line meter for measuring large water volumes in close conduits.—Hersey-Sparling Meter Co.

Circle No. R-253 on Reader Service Card

Manganese Removal

Published case history reports describe actual water department experiences using potassium permanganate for iron and manganese removal.—Carus Chemical Co., Inc.

Circle No. R-254 on Reader Service Card

Manganese Removal

8-page illustrated brochure describes Carox (T.M.) Potassium Permanganate technique for manganese removal; includes full instructions for evaluation of water for permanganate demand.—Carus Chemical Co., Inc.

Circle No. R-255 on Reader Service Card

Manhole Frames and Covers

Descriptive literature and catalog illustrating standard size manhole frames and covers, cast iron inlets and other municipal castings.—Opelika Foundry Co., Inc.

Circle No. R-256 on Reader Service Card

Materials Handling

Catalog 380.010 describes methods of handling dry, free-flowing solids. In text and illustrations, it shows problems of moving material, methods of bin design, and choice of hoppers and spouts.—Wallace & Tiernan, Inc.

Circle No. R-257 on Reader Service Card

Mechanical Joints

A catalog describing different types of pipe and fittings connected with mechanical joints. — Alabama Pipe Co.

Circle No. R-258 on Reader Service Card

Mechanical Joints

Booklet includes dimensions and weights of mechanical joint cast iron pipe and fittings. — U. S. Pipe & Foundry Co.

Circle No. R-259 on Reader Service Card

Mechanical Rack Rake

Booklet describing operation of custom-built Newport News mechanical rakes for cleaning trash racks at water intakes. Details on rack hoist machinery, attachments for special trash cleaning problems, and methods of trash removal are given. Diagrams and representative specifications on typical installation arrangements are shown. — Newport News Shipbuilding & Dry Dock Co.

Circle No. R-260 on Reader Service Card

Meter Boxes

Brochure and catalog illustrating cast iron meter boxes, manhole frames and covers, cast iron inlets and other municipal castings.—Opelika Foundry Co., Inc.

Circle No. R-261 on Reader Service Card

Meters, Magnetic Drive

Bulletin DER-961 fully describes the new Badger Easy-Read, magnetic drive, disc type water meter. The Easy-Read features: Easier to read, non-fogging straight registers with ¼" high digits. No stuffing box to leak. Magnetic drive with powerful, permanent, ceramic magnets. The register assembly may be removed, even under water without disturbing the meter in the line and it can be mounted in any of four positions for most convenient reading. Made in Split Case type in sizes ⅝" through 2", and frost protective type in sizes ⅝" through 1" x 1¼".—Badger Meter Mfg. Co.

Circle No. R-262 on Reader Service Card

Meters, Remote Reading

The Badger Read-o-Matic water meters gets you "IN" OUTDOORS. Bulletin R-2000 fully describes this revolutionary meter that brings water meter reading out in the open. It assures 100% meter reading in ½ the time. No more inconvenienced customers, in-house accidents, lock outs or access problems. They are fully adaptable for residential or industrial installations. The registers may be as far as ½ mile away from the meter.—Badger Meter Mfg. Co.

Circle No. R-263 on Reader Service Card

Meters, Remote Reading

New Tele-Read remote meter reading system is offered on American Water Meters. The reading is obtained from outside the house with the meter located at any convenient position inside, connected to an outside plug socket by a cable. The meter reader carries a read-out unit which is inserted into the socket for fast accurate residential meter readings.—Buffalo Meter Co., Inc.

Circle No. R-264 on Reader Service Card

Meters, Remote Reading

Bulletin 728 describes remote reading meter that employs use of 15 second cycle, time impulse transmitter to actuate electric receiver in remotely located recording and totalizing receiver. Multiple number of receivers can operate from the transmitter.—Simplex Valve & Meter Co.

Circle No. R-265 on Reader Service Card

Meter Repair

This complete, well illustrated 16-page manual for the water meter shop tells how to set up a repair and test program, how to lay out the shop, and step-by-step repair instructions. Indicate frost-proof or split case meters.—Neptune Meter Co.

Circle No. R-266 on Reader Service Card

Use Accompanying Reply Card to Obtain Copies of these Bulletins.

Meter Setting Equipment

Catalog No. 62 contains a complete listing of water meter accessories such as Meter Boxes, Meter Box Covers, Meter holding devices, Yokes, Coppersetters, Meter Valves, Couplings, Test Benches, Calibrated Tanks, etc. —The Ford Meter Box Co., Inc.

Circle No. R-267 on Reader Service Card

Meters, Sewage Gas

Bulletin M-258 covers rotary positive displacement meters for measuring all types of gases, at flow rates ranging from 4000 CFH to 1,000,000 CFH, designed for service at 25, 60, and 125 PSIG.—Roots-Connersville Blower.

Circle No. R-268 on Reader Service Card

Meter Testing, Water

A 40-page book on methods and equipment for testing meters, including information on meter shop layout, meter performance, and a bibliography on meter maintenance.—The Ford Meter Box Co., Inc.

Circle No. R-269 on Reader Service Card

Meters, Total Flow

The Stevens Model 61M Total Flow Meter is described in Bulletin 28, Second Edition. This new instrument incorporates the essential features of the previous Model 60M Total Flow Meter and, in addition, is equipped with gearing to adapt to a variety of flow ranges and cams are available for use with over 15 measuring flumes or weirs. This float actuated instrument indicates water, sewage or other liquid flow in mgd through a measuring flume or weir and totalizes in gallons on a 5 digit counter-totalizer. Peak flow is indicated by a sliding red index on the scale.—Leupold and Stevens Instruments, Inc.

Circle No. R-270 on Reader Service Card

Meters, Water

General catalog illustrates and describes Badger, Disc meters, frost proof and split case types, 5/8" through 4" sizes. Compound meters 2" through 10" sizes. Turbine meters 2" through 12" sizes. Multiple meter testers and meter coupling yokes.—Badger Meter Mfg. Co.

Circle No. R-271 on Reader Service Card

Meters, Water

Completely new fully-illustrated catalog of American Water Meters of disc type for residential, commercial and industrial services. Exclusive features of simplicity, breakable bronze frost bottom, easy assembly are described. Frost protected and non-frost models, 5/8"-6" sizes.—Buffalo Meter Co., Inc.

Circle No. R-272 on Reader Service Card

Meters, Water

Hersey Water Meters and Sparling Meters & Instruments. General catalog provides full information on disc meters (cold water) sizes 5/8" through 6", disc meters (hot water) sizes 5/8" through 3", compound meters (bronze case) 2" through 6", compound meters (iron case) 8" and 10", detector meters (fire service) 3" through 10" x 12", torrent meters (turbine type) 2" through 12", detector checks, 2" through 10".—Hersey-Sparling Meter Co.

Circle No. R-273 on Reader Service Card

Meters, Water

This catalog gives details and specifications of Trident meters from 5/8 to 16" in size. Frostproof and split-case meters for household use, style 3 meters for intermediate flows, and larger compound, crest and Protestus lire service meters are also covered.—Neptune Meter Co.

Circle No. R-274 on Reader Service Card

Meters, Water

Bulletin 426 discusses Trident Model 60 Water Meter and its advantages. Meter has accessible change gears permitting adjustment of registration. Register is hermetically sealed, magnetically driven. Can be repaired, reset and resealed in field. Sealed gear train also has magnetic drive, eliminating leaks. Sealed registers and gear trains fit older Tridents.—Neptune Meter Co.

Circle No. R-275 on Reader Service Card

Microbiological Analysis of Water

Manual ADM-10 outlines the advantages inherent in the membrane filter technique in procedures for use in the microbiological analysis of water and milk. Also included in the 20-page laboratory manual are staining techniques and the biologic examination of water samples.—Millipore Filter Corp.

Circle No. R-276 on Reader Service Card

Microstraining

A 4-page brochure illustrating the 120 MGD Microstraining Installation at Denver, Colorado. Describes the project, test, results, contract, installation plan and benefits. Request "The Denver Story" Bulletin.—Glenfield & Kennedy, Inc.

Circle No. R-277 on Reader Service Card

Mixflo Pumps

A 16-page bulletin on mixflo pumps for irrigation, drainage, sewage disposal, condenser circulating and low water supply. Performance curves and drawings are also included.—Worthington Corp.

Circle No. R-278 on Reader Service Card

Modern Sewage Treatment

Bulletin 6041 describes the distinguishing characteristics, types, sizes, applications and operation of major Dorr-Oliver sewage treatment equipment and presents a number of typical plant flow-sheets. Also included are photographs and line and wash drawings of various units.—Dorr-Oliver, Inc.

Circle No. R-279 on Reader Service Card

Modular Controller

For Water Filtration Plants—eliminates separate differential producing venturi, drives and linkages, excessive piping, pilot valves, floor drains, separate actuators, and operating water supply. A unique but proven way to obtain close control of effluent, and a simplified, efficient, and very economical control unit. Described in bulletin 951.—Simplex Valve & Meter Co.

Circle No. R-280 on Reader Service Card

Monorake

This 12-page bulletin, No. 6001-R, presents the Dorroco Monorake. It describes the design, types and sizes, operation and advantages of this mechanism for cleaning rectangular sedimentation basins and tabulates

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actual maintenance costs from a number of installations. — Dorr-Oliver, Inc.

Circle No. R-281 on Reader Service Card

Motors, Synchronous

Tells features of synchronous motors which help maintain efficiency at fractional or full loads, correct power factor, increase system output, and improve plant voltage regulation. Available in ratings above 1 hp rpm at speeds of 450 or less.—Allis-Chalmers Mfg. Co.

Circle No. R-282 on Reader Service Card

Motors, Variable Speed

This informative color bulletin describes the distinguishing characteristics, types, sizes, and operation of U. S. Motors' "Varidrive." The self-contained unit, embodying a motor and built-in speed transmission, allows changes of speed while operating and is available in a range of horsepower from ¼ to 100.—U. S. Electrical Motors, Inc.

Circle No. R-283 on Reader Service Card

Motion Safety Switch

4-page Bulletin MS-3 describes an improved type motion safety switch for protecting machines, equipment and processes against damage resulting from stoppage or reduced speed. Bulletin describes design, installation and operation of the switch.—Fuller Co.

Circle No. R-284 on Reader Service Card

Multi-Function Sewage Treatment

Bulletin SM-1016 describes Oxigritter sewage treatment unit, a new product that combines grit removal, pre-aeration and clarification in one double compartment circular tank. In many sewage treatment operations, Oxigritter units can eliminate need for separate grit removal equipment. —The Eimco Corp.

Circle No. R-285 on Reader Service Card

Municipal Sanitation

Bulletin No. 6043 "Seven Developments for Municipal and Industrial Sanitation" assembles for review in a single brochure data on seven major D-O equipment designs and process developments introduced in the past three years. It includes photographs, line and wash drawings and descriptive sketches of each development.—Dorr-Oliver, Inc.

Circle No. R-286 on Reader Service Card

Municipal Supplies

General Catalog No. 163 presents extensive line of municipal supplies offered by this manufacturer.—W. S. Darley & Co.

Circle No. R-287 on Reader Service Card

Odor and Grease Control

Bulletin describes "Cifon," an emulsifiable chlorobenzene especially formulated for odor, grease and organism control. For relief of overloaded treatment plants. Also special modified Cifon formulations for specific industrial waste problems.—Division of Pollution Control Chemicals, Fine Organics, Inc.

Circle No. R-288 on Reader Service Card

Odor Control

Technical bulletin describes "Odorwilt," a non-toxic, surface and air active deodorant for neutralizing and masking odors from lagoons, oxidation ponds, sludge storage tanks, pump and lift stations, industrial plants. Special formulations for specific needs. — Division of Pollution Control Chemicals, Fine Organics, Inc.

Circle No. R-289 on Reader Service Card

Odor Control

Literature explains how the use of Sanfax DX-85 in Sewage Treatment Plants chemically combats objectionable odors at the source.—Sanfax Corp.

Circle No. R-290 on Reader Service Card

Oxidators

Eimco-Process Oxidators combine sedimentation and aeration in one tank, the air mixing and recirculating previously settled sludge and floc with the influent Bulletin SM-1005. —The Eimco Corp.

Circle No. R-291 on Reader Service Card

Oxidator-Aerator

Bulletin on the American "Mechanicomb" tells how this mechanical, pressure and turbine type Oxidator-Aerator provides total oxydation through complete aeration-mixing, agitation and diffusion, utilizing sparged air and atmospheric air.—American Well Works.

Circle No. R-292 on Reader Service Card

Packaged Pump Stations

Illustrated bulletin PS-60R provides the specifications and operating features of the duplex pump stations. On-the-job photographs show installation details.—Tex-Vit Supply Co.

Circle No. R-293 on Reader Service Card

Package Treatment Plants

Folder describes the Comple Treator, a self-contained complete waste treatment facilities for small plants.—Dorr-Oliver, Inc.

Circle No. R-294 on Reader Service Card

Package Treatment Plants

New circular steel sewage treatment plant. Smaller, more compact, for shopping areas, resorts, factories, motels, home groups, etc. will accommodate 10-500 people with capacities of 1,000, 3,000, 5,000 G.P.D. Bulletin 136.—Chicago Pump.

Circle No. R-295 on Reader Service Card

Package Treatment Plants

Sparjair compact sewage treatment plants are described in bulletin 19-S-94. Gives process details, typical layouts and specifications along with installation photos. — Walker Process Equipment Inc.

Circle No. R-296 on Reader Service Card

Packaged Waste Treatment Plants

Bulletin describes the "American" "Oxy-Pak" plants including application and engineering data for population equivalents up to 3000.—American Well Works.

Circle No. R-297 on Reader Service Card

Parshall Flume

Polyester Resin Bonded glass fiber construction. Full length flumes, eliminate form work and excess concrete. Designed for strength, rigidity, light weight, long life, and dimensional

accuracy. Described in Bulletin 802.—Simplex Valve and Meter Co.

Circle No. R-298 on Reader Service Card

PeriFilter System

Combines conventional water pretreatment and rapid sand filters in a single unit for economies in handling 0.2 to 20 MGD. Buletin #9042 offers choice of pre-treatment mechanisms with annular filter bed for all conditions.—Dorr-Oliver Inc.

Circle No. R-299 on Reader Service Card

Pipe, Cast Iron Pressure

Facilities brochure, describing cast iron pressure pipe in 20′ lengths for water and gas. Brochure describes area serviced, selection of pipe joints available, layout of the plant and method of manufacture.—Griffin Pipe Div.

Circle No. R-300 on Reader Service Card

Pipe Cleaning and Maintenance

Exclusive "Planalyzed Contract Cleaning" services by APCO are presented in brochures with details of cleaning and maintenance programs for municipal sewer and waterm systems, gas lines and piping of all types. Literature outlines all phases of APCO's cleaning services, including details of inspection and analysis of troubled areas, presentation of plan and cost without charge, and the engineering cleaning program.—American Pipe Cleaning Co.

Circle No. R-301 on Reader Service Card

Pipe Cutters

Catalog No. 42 illustrates and describes Ellis heavy duty Pipe Cutters, an all-purpose tool, with interchangeable cutter wheels for all types of pipe—cast iron, steel, as well as vitreous clay pipe.—Ellis & Ford Mfg. Co.

Circle No. R-302 on Reader Service Card

Pipe Detectors

Bulletins WS-1, WS-2, and WS-3, provide complete information on the latest type pipe detector, box and valve detector, and pipe-leak detector respectively. Also available is a 24-page manual (WS-4) on common problems encountered with pipe and leak detection work, and how to solve them.—Computer Measurements Co., Detectron Div.

Circle No. R-303 on Reader Service Card

Pipe Finders, Transistorized

Literature describes Fisher's 1960 model M-Scope Pipe Finders featuring hermetically sealed transistors and printed circuits, vastly superior to vacuum tubes and circuits in conventional models.—Fisher Research Laboratory, Inc.

Circle No. R-304 on Reader Service Card

Pipe Locators, Transistorized

General Catalog No. 163 describes and illustrates this company's extensive line of pipe and leak locators.—W. S. Darley & Co.

Circle No. R-305 on Reader Service Card

Pipe, K&M Sewer

Asbestos-Cement sewer pipe is described in 4-page, two-color folder, AP-22. Literature provides general information on the installation and performance of gravity sewer systems using asbestos-cement pipe. AP-16, a companion piece, provides information in detailed illustrations which show the action of K&M's patented, exclusive Fluid-Tite coupling.—Keasbey & Mattison Co.

Circle No. R-306 on Reader Service Card

Pipe, Plastic

TR-270A, a comprehensive illustrated brochure on J-M Supreme Pipe—a polyethylene pipe—contains table of properties, working pressures, methods of cutting, connecting, installing, testing and backfilling. TR-273A, a 4-page illustrated folder describing Johns-Manville ABS pipe. Also available on this pipe is Material Specification ABS-600.—Johns-Manville.

Circle No. R-307 on Reader Service Card

Pipe, Pressure

Asbestos-Cement water pressure pipe's ability to deliver clear, pure water for domestic or industrial uses is described in a 4-page, two-color folder, AP-27. The literature details advantages of asbestos-cement along with installation techniques to save time and money. Pipe handles easily; patented, exclusive Fluid-Tite coupling assures tightly sealed joints under various ground conditions.—Keasbey & Mattison Co.

Circle No. R-308 on Reader Service Card

Pipe, Sewer, Asbestos-Cement

Transite® Sewer Pipe made of asbestos-cement, available in 11 different diameters ranging from 6″ to 36″ and in 5 new crushing strengths to permit greater efficiency in system design. Ring-Tite® Coupling, designed for high-speed assembly, provides tight, long-lasting seal. Easy-to-assemble Transite sewer fittings with Ring-Tite assembly also furnished. For complete information, write for brochure TR-165A (Transite Sewer Pipe), TR-94A (Sewer Design Flow Chart), DS 366 (a material specification) and DS 370 (an installation specification). —Johns-Manville.

Circle No. R-309 on Reader Service Card

Pipe, Steel

A series of seven, 8-page brochures tell how steel pipe meets the 7 essential requirements for a water pipe line: 1. Outstanding strength, 2. Extreme durability and long life, 3. Economy of installation and maintenance, 4. High carrying capacity, 5. Ductility and adaptability, 6. Great reliability and resiliency, and 7. Bottletight joints.—Steel Plate Fabricators Association.

Circle No. R-310 on Reader Service Card

Pipe, Underdrain, Asbestos-Cement

TR-246A, a 4-page folder describes and illustrates Transite Underdrain pipe, a perforated pipe for subsurface drainage and control of ground water. Also available is Material Specification DS-927 with, among other data, crushing strength requirements, detailed perforation requirements, inspection and test requirements.—Johns-Manville.

Circle No. R-311 on Reader Service Card

Pipe, Water, Asbestos-Cement

Installation manual for Eternit® pipe and Eternit Selftite® couplings.

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Describes inspection, unloading and stacking of pipe, preparation of trench, assembling pipe, service connections, testing, repairing damaged pipe. Also table of dimensions of Eternit pipe and couplings.—Indussa Corp.

Circle No. R-312 on Reader Service Card

Pipe, Water, Asbestos-Cement

Bulletin ET-1 covers standard specifications for Eternit® pressure pipe, classes 100, 150 and 200 psi, sized 3" to 16", and Eternit Selftite® couplings. Standards include requirements for material, dimensions, hydrostatic, flexural and crushing strengths, inspection and test procedures, marking and preparation for shipment.—Indussa Corp.

Circle No. R-313 on Reader Service Card

Pipe, Water, Asbestos-Cement

The installation, operation and maintenance economies of Transite® Pipe and the Ring-Tite® Coupling for pressure water lines are described and illustrated in four pieces of literature available to the water utilities management. They include (1) DS-335—a material specification; (2) DS-348, an installation specification; (3) TR-15A—a Friction Loss of Head and Flow Powergraph; (4) TR-160A, in service characteristics and case histories of Transite Water Pipe. Tables of weights, sizes and pressure classes also included. — Johns-Manville.

Circle No. R-314 on Reader Service Card

Pipe, Water, Reinforced

Sixteen-page Technical Bulletin 100 deals with Federal Specification INT. FS-SS-P-00385 covering cement mortar lined and reinforced cement mortar coated welded steel pressure pipe from 4 to 42 in. in diameter for use in water transmission, distribution and feeder pipelines. This manufacturer's STEELCOR CEMCOTE is designed to this Federal Specification. — Southern Pipe Div., U. S. Industries, Inc.

Circle No. R-315 on Reader Service Card

Plant Valves, Filtration

Bulletin W-18A describes G-A Filter Drain Valves, Backwash Valves and Rewash Valves specifically designed for these functions. Indicators rods connect valves to gauges on operating table. Backwash and rewash valves have same radius elbow fitting, thus eliminating the price of this fitting, reducing pressure drop, and saving expensive building costs by requiring less space. —Golden-Anderson Valve Specialty Co.

Circle No. R-316 on Reader Service Card

Plastic Pipe

A new bulletin describes the new Ace Riviclor Chemical-Resistant Plastic Pipe, Fittings and Valves. The bulletin includes technical properties, a table of resistance to chemicals, data on sizes, pressures, dimensions, prices for pipe, fittings and valves from ½ to 2 in. Instructions for treading, forming and other installation operations are also given. —American Hard Rubber Division, American Corp.

Circle No. R-317 on Reader Service Card

Plunger Pumps

Bulletin No. 1002 describes plunger type sludge pumps in capacities of up to 500 gpm against total dynamic heads of up to 231 ft. Also pump selection chart, motor selection chart and sample specifications.—Ralph B. Carter Co.

Circle No. R-318 on Reader Service Card

Pneumatic Ejectors

Bulletin No. 5408 gives a complete description of pneumatic ejector systems including principles of operation, construction features, operating arrangements, methods of selection, air compressor and tank sizing, and layout dimensions for both single and duplex stations ranging in capacity from 30 gpm to 600 gpm.—Ralph B. Carter Co.

Circle No. R-319 on Reader Service Card

Pneumatic Ejectors

The factory-built "Du-O-Ject" duplex sewage lift station is described in Bulletin 616-B presenting the design features and operation of this dependable unit with exclusive "No-Fail" Electrode System. Bulletin explains how "No-Fail" Electrode System eliminates grounding and insulation failures which put conventional ejectors out of operation.—Smith & Loveless, Div.—Union Tank Car Co.

Circle No. R-320 on Reader Service Card

Pneumatic Ejectors

The factory-built "Mon-O-Ject" simplex pneumatic ejector sewage lift station is described in Bulletin 615-D presenting operational characteristics and design features of this low-cost lift station. The "Mon-O-Ject" is available with exclusive "No-Fail" Electrode System. Bulletin is included in 100-page engineering data manual. —Smith & Loveless, Div.—Union Tank Car Co.

Circle No. R-321 on Reader Service Card

Pneumatic Ejectors

Exclusive "Way-O-Matic" sewage lift station, described in Bulletin 610-D, has a superior patented control system to provide maximum dependability—actually "weighs" the sewage, provides trouble-free operation. Bulletin included in 100-page engineering data manual.—Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-322 on Reader Service Card

Pneumatic-Master Control System

An outline and brief description of the Simplex Pneumatic Master Control System for water filtration plants is found in Technical Bulletin 751, which contains an interesting flow diagram showing locations of vital equipment items for this system.—Simplex Valve & Meter Co.

Circle No. R-323 on Reader Service Card

Pneumatic Transmitter

Bulletins 753, 754 and 755 describe pneumatic transmission systems giving linear signals for rate of flow, loss of head and level. Designed for 3—15 psi signal.—Simplex Valve & Meter Co.

Circle No. R-324 on Reader Service Card

Pneumatic Transmitters and Receivers

Bulletin 281-01.201-1 describes pneumatic transmission of flow, normally used in conjunction with such differential producers as Venturi Tubes, Dall Flow Tubes, Venturi Nozzles or Orifice Plates; Bulletin 282-09.201-1 describes Model 289-09,

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a panel mounted Pneumatic Totalizer. —Builders-Providence Div., B-I-F Industries.

Circle No. R-325 on Reader Service Card

Potassium Permanganate

Published case history reports describe actual water department experiences using potassium permanganate for taste and odor control, iron and manganese removal.—Carus Chemical Co., Inc.

Circle No. R-326 on Reader Service Card

Potassium Permanganate

8-page illustrated brochure discusses taste and odor control, iron and manganese removal utilizing the Carox (T.M.) Potassium Permanganate treatment technique. Includes full instructions for evaluation and use.—Carus Chemical Co., Inc.

Circle No. R-327 on Reader Service Card

Power Sewer Cleaners

Current catalog illustrates and describes the improved models of Sewerkings—all power, automatic, cable type machines which reduce sewer cleaning costs 50%-75% by one-man operation and manhole to manhole reach.—O'Brien Manufacturing Corp.

Circle No. R-328 on Reader Service Card

Precipitators

Bulletin 4836 describes Permutit Type M Precipitator, a new solids-contact type clarifier of unique simplified design. Water-jet powered agitator requires no overhead support, catwalks, or agitator drive motors, mounts or bracing. May be installed in new or existing round basins. Flow rate range from 150 gpm to 7000 gpm.—The Permutit Co., a division of Pfaudler Permutit Inc.

Circle No. R-329 on Reader Service Card

Prestressed Concrete Tanks

16-page general brochure discussing advantages and features of prestressed concrete circular tanks. Basic design and construction procedures, varied uses, and economy of these structures fully explained. Text accompanied by diagrams, photographs, and capacity chart.—The Preload Co., Inc.

Circle No. R-330 on Reader Service Card

Products and Services

4-page brochure presents the many and diversified products and services offered by General American Transportation Corp., through its numerous divisions. Among the subsidiaries serving the water and sewage field are: Fuller Co.; Sutorbilt Corp.; and Dravco Division.—General American Transportation Corp.

Circle No. R-331 on Reader Service Card

Proportioning Pumps

Bulletin 420.200 describes new line of plunger pumps, suitable for feeding all chemical solutions used in water and sewage treatment. Pumps have minimum range of less than 1 gallon per hour. Various units may be "ganged" giving almost limitless maximum capacity of several thousand gph. Pneumatic controller described in Catalog 420.690, allows pumping rate to be regulated by other equipment, such as dry feeders, or any external air supply.—Wallace & Tiernan Inc.

Circle No. R-332 on Reader Service Card

Protective Coatings

Literature describes this manufacturer's Amercoat No. 99, a new high build, corrosion resistant, vinyl coating recommended for use on tank exteriors and all types of structural steel. —Amercoat Corp.

Circle No. R-333 on Reader Service Card

Protective Coatings

13-page illustrated booklet CAC-11-598 describes the complete line of Coal-Tar Protective Coatings offered by this manufacturer. Because of their inherent resistance to water penetration, chemicals and stress conditions, these coatings find wide use in a variety of industrial, utility and municipal installations. — General Chemical Div., Allied Chemical Corp.

Circle No. R-334 on Reader Service Card

Pumping Stations, Sewage

Bulletin No. KSM-5, a description of Komline-Sanderson Prefabricated Sewage Pumping Stations, with cutaway line drawings and motor horsepower selection chart, also suggested form of specification.—Komline-Sanderson Eng. Corp.

Circle No. R-335 on Reader Service Card

Pumps

Bladeless sewage and trash. Bulletin 5400K—Covers horizontal and vertical bladeless sewage and trash pumps. Diagrams, dimensions, selection tables and performance curves shown.—Fairbanks, Morse & Co.

Circle No. R-336 on Reader Service Card

Pumps

Centrifugal split case single stage, Bulletin 5874-4, describes these pumps particularly recommended for municipalities to operate at high speeds against heads which generally require pumps of two stage type.—Fairbanks, Morse & Co.

Circle No. R-337 on Reader Service Card

Pumps

A complete line of self-priming centrifugals, sewage and sludge pumps. Bulletins and specifications available. —The Gorman-Rupp Co.

Circle No. R-338 on Reader Service Card

Pumps, Axial and Mixed Flow

Especially applicable for pumping water at high volumes at low head. Bulletin includes cross sections, construction features and suggested installation arrangements. — C. H. Wheeler Mfg. Co.

Circle No. R-339 on Reader Service Card

Pumps-Centrifugal

Bulletin carries comprehensive operating data on ACAP pump for handling liquids or hygroscopic solids in suspension under variable capacity and head requirements.—Allis-Chalmers Mfg. Co.

Circle No. R-340 on Reader Service Card

Pump-Controllers

This bulletin describes purged air and static pump controllers, and gives the different applications for each type. Controllers are suitable for both sewage and clear water.—Healy-Ruff Company.

Circle No. R-341 on Reader Service Card

Pumps, Deep Well Vertical Turbine

This bulletin, in color, shows a cross-section of the Layne Vertical Turbine pump and applications for it.

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Both the water and oil lubricated pump bulletins available.—Layne & Bowler, Inc.

Circle No. R-342 on Reader Service Card

Pumps, Diaphragm

Cat. 410.015 describes single and dual-head mechanical diaphragm metering pumps. With capacities of 4 to 250 gallons per day per head, against pressures to 100 psi, these pumps handle all chemicals used in water and sewage treatment. Dual-head models may be used to double capacities or for proportional pumping. Each head is individually adjustable while pump is running or stopped.—Wallace & Tiernan Inc.

Circle No. R-343 on Reader Service Card

Pumps, Dry Vacuum

Dry vacuum pumps, rotary positive displacement described in Bulletin RAS-261. Vacuums to 15" Hg. Cycloidal Blowers for vacuum service are presented in Bulletin VP-158—Capacities from 500 to 13,000 cfm, at vacuums to 20" Hg. Spiraxial® compressors as described in Bulletins LAH-158 and LAL-458. — Roots-Connersville Blower.

Circle No. R-344 on Reader Service Card

Pumps, Heavy-Duty Submersible

Literature describes Kenco's new Model 119-A44 heavy-duty submersible pump which is doing an outstanding job of protecting underground transformer installations. Equipped with oil-filled, completely sealed ½ hp motor that delivers a pumping capacity of 3300 gph at a 10 ft. head.—Kenco Pump Division.

Circle No. R-345 on Reader Service Card

Pumps, Freflo

A 12-page bulletin covering horizontal and vertical Freflo pumps for handling sewage and industrial wastes. It contains rating curves for 18 pump models. Also included are charts for selection of shafting for use with vertical pumps. Complete dimension data are given for all pump models.—Worthington Corp.

Circle No. R-346 on Reader Service Card

Pump Motors and Drives

Bulletin F-2002 provides condensed specification data, illustrations, cutaways, diagrams and descriptions of 16 lines of specialized pump motors and gear drives. Illustrated index and descriptive tables make it easy to locate the type of motor, h.p., thrust and other facts required to select the drive to fit each pump need.—U. S. Electrical Motors, Inc.

Circle No. R-347 on Reader Service Card

Pumps, Non-Clog Sewage

8-page bulletin contains description, features, sectional views, selection charts, and specifications on complete line of horizontal and vertical, close-coupled and flexible-coupled non-clog pumps. Designed with large streamlined passageways and scientifically balanced impellers for highest efficiency in handling of heavy liquids, solids in suspension, effluent, by-products, and wastes. Capacities to 9000 gpm. Heads to 150 ft. Solids size to 6".—Aurora Pump Div., The New York Air Brake Co.

Circle No. R-348 on Reader Service Card

Pumps, Non-Clog Submersible

Bulletin illustrates and describes line of fully submersible motor-pump units applicable to a wide variety of applications such as industrial by-products, lift stations, sewage plants, industrial processing, municipal pumping stations, and drainage. Especially designed to accommodate locations where area must be free of obstructions, where dirt, dust, or explosive fumes are present, where available space is below floor, where tampering must be eliminated, where there is threat of flood, or where airborne noise and vibration must be reduced. Capacities to 1100 gpm. Heads to 90 ft. Solids size to 3".—Aurora Pump Div., The New York Air Brake Co.

Circle No. R-349 on Reader Service Card

Pumps, Sewage

Sewage and Sludge Pumps, vertical and horizontal dry pit centrifugals, for capacities to 24,000 gpm, sizes from 3" to 24" are described in series catalogs. Submersible and Vertical Submerged Units also available.—Yeomans Brothers Co.

Circle No. R-350 on Reader Service Card

Pumps, Sewage

New specification sheets cover horizontal and vertical conventional and bladeless sewage and trash pumps. Diagrams, dimensions, selection tables and performance curves shown. —Fairbanks, Morse and Co.

Circle No. R-351 on Reader Service Card

Pumps, Sewage and Sludge

The company has a series of bulletins giving data, design features, and specification information on sewage and sludge pumps.—Chicago Pump.

Circle No. R-352 on Reader Service Card

Pumps, Sewage and Sludge

Bulletin No. KSP-2, a 4 page, 2 color description of Komline-Sanderson dual-valve plunger and diagram pumps, with illustrations and plunger pump selection chart.—Komline Sanderson Engineering Corp.

Circle No. R-353 on Reader Service Card

Pumps, Sewage and Sludge

Bulletin No. KSP-3, a description of Komline-Sanderson dual valve plunger pumps, with dimension tables and pump size and motor horsepower selection chart. — Komline-Sanderson Eng. Corp.

Circle No. R-354 on Reader Service Card

Pumps, Sewage and Sludge

Construction details, cross section drawings, performance data and suggested methods of mounting are included in a series of five bulletins.—C. H. Wheeler Mfg. Co.

Circle No. R-355 on Reader Service Card

Pumps, Sewage Sump

Literature describes Kenco's new Model 139 sewage sump pump. Completely submersible and equipped with ½ hp motor, it can pump 8600 gph at a 5 ft head, or 6800 gph at 10 ft.—Kenco Pump Division.

Circle No. R-356 on Reader Service Card

Pumps, Single Passage Non-Clog

8-page bulletin contains specifications, selection data, features, and

sectional views of complete line of Non-Clog pumps equipped with exclusive Mono-Vane single vane design (patented) impellers. Dynamic balance is automatically maintained through entire curve. Impeller can be trimmed to suit various head and capacity requirements and still retain proper balance. Requires no separate counterbalance. Ideal for handling long, stringy materials. — Aurora Pump Div., The New York Air Brake Co.

Circle No. R-357 on Reader Service Card

Pumps, Sludge

Bulletin 191—Describes in full the capacities, heads, horsepowers, and dimensions of this screw conveyor, positive displacement "Scru-Flo" Sludge Pump.—Chicago Pump.

Circle No. R-358 on Reader Service Card

Pumps, Split-Case Centrifugal

Bulletins illustrate and describe complete line of horizontal and vertical mounted single stage double suction pumps of horizontally split-case design. Also include vertical and horizontal mounted two-stage opposed suction pumps of horizontally or diagonally split-case designs. Features include scientifically balanced impellers, bearing centers, precision finished passages, and advanced design which provide maximum operating efficiency. Suction and discharge located in bottom half of casing provide maximum ease of inspection, cleaning or maintenance.—Aurora Pump Div., The New York Air Brake Co.

Circle No. R-359 on Reader Service Card

Pumps, Split-Case Centrifugal

Bulletin 5000, details of construction with selection tables covering capacities up to 7000 gpm and heads up to over 300 feet.—The Deming Company.

Circle No. R-360 on Reader Service Card

Pumps, Sump

Bulletin SU-56 describes a self-contained air motor driven portable sump pump for removing clean or dirty water, sewage or sludge from cellars, excavations, ditches, trenches and settling basins.—Schramm, Inc.

Circle No. R-361 on Reader Service Card

Pumps, Sump

Bulletin 8-SP-11 describes "High & Dry" Sump Pumps for home basements and industry use.—The Gorman-Rupp Co.

Circle No. R-362 on Reader Service Card

Pumps, Sump

Bulletins contain description, illustrations, and specifications on complete line of heavy duty sump pumps. Also include vertical non-clog pumps designed for wet pit service. Units engineered to specific requirements. Ideal for handling heavy or viscous liquids and solids in suspension. Available in special alloys for handling corrosive liquids. Capacities to 1500 gpm. Heads to 170 ft.—Aurora Pump Div., The New York Air Brake Co.

Circle No. R-363 on Reader Service Card

Pumps, Two-Stage

Applicable for high pressure water supply. Bulletin includes construction details, performance curves and dimensions.—C. H. Wheeler Mfg. Co.

Circle No. R-364 on Reader Service Card

Pumps, Vertical Turbine Deep Well

Bulletins on both water lubricated and oil lubricated turbine available. —The Deming Company.

Circle No. R-365 on Reader Service Card

Pumps, Volute-Type

Bulletin includes cross section drawings, and construction details of Volute-Type Pumps for sewage, drainage, water supply. — C. H. Wheeler Mfg. Co.

Circle No. R-366 on Reader Service Card

Pumps, Water

Bulletins cover the complete line of "American" end suction axial flow pumps, split-case centrifugal pumps, deep well turbine pumps, airlift pumps. Also bulletins on "American" sewage and sludge pumps.—American Well Works.

Circle No. R-367 on Reader Service Card

Purge Meters

A complete range for glass-tube and armoured purge meters is described in catalog 510.200. Glass-tube meters are used for purging, venting, and sampling applications, for liquid level control, and specific gravity determination. Armored purge meters allow hazardous fluids to be easily metered.—Wallace & Tiernan, Inc.

Circle No. R-368 on Reader Service Card

Purification Systems

6-page bulletin describes this company's method of assembling predesigned biological sewage treatment plants from concrete blocks and prefabricated components. The brochure includes photographs and diagrams of a complete sewage treatment plant; multiple septic tank systems; Imhoff tank systems; and a trickling filter plant.—American Schreiber Co.

Circle No. R-369 on Reader Service Card

Railroad Car Shakers

Link-Belt Company's new one-man operated Railroad Car Shaker which incorporates a new low-frequency vibration shaker mechanism for fast, economical unloading of hopper bottom cars at the rate of 8 to 10 an hour is the subject of the 6-page Folder 2745. The shaker mechanism transmits low-frequency vibrations to the top of car sides. No undesirable sidewise movement is produced. Energy of the lengthwise impacts is transmitted through the car, loosening the material so it can flow freely through the hopper openings in the bottom—Link-Belt Co.

Circle No. R-370 on Reader Service Card

Rate Controllers

Bulletins 600-G6B and 600-J9A describe Rate of Flow Controllers Models RCE and RCB-T developed especially for water works service, for maintaining a constant flow of filter effluent or backwash water.—Builders-Providence Div., B-I-F Industries.

Circle No. R-371 on Reader Service Card

Reactor-Clarifier

New 24-page Bulletin SM-1006 describes versatile reactor-clarifier treatment units for obtaining high removals in the pre-treatment of sewage or for secondary treatment of sewage with chemical coagulants. Built in a wide range of types and sizes, including units suitable for treating industrial wastes to condi-

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tion the water for re-use.—The Eimco Corp.

Circle No. R-372 on Reader Service Card

Recorders, Chlorine Flow

Described in Specification Sheet 70×1150. Sheet outlines operation of this instrument and lists accessories and typical specifications.—Fischer & Porter Co.

Circle No. R-373 on Reader Service Card

Recorder-Totalizer

A 4-page bulletin describing the proper and efficient applications of recorder-totalizers. — Standard Instrument Corp.

Circle No. R-374 on Reader Service Card

Recorders, Type F

Bulletin 24, 11th Edition describes the recently redesigned Type F Stevens Recorder, a general purpose instrument for recording fluctuations of any liquid surface, such as ground water levels in deep wells, for stream gaging, irrigation, water supply, sewage and oil production. Applications data and instrument specifications are contained in eight pages of illustrations and descriptive data. Also described is the Stevens Type FM weight driven recorder.—Leupold & Stevens Instruments, Inc.

Circle No. R-375 on Reader Service Card

Registers, Read-o-Matic

Bulletins R2000 and DR135 illustrate water meter registers that take the meter reader out of the house. The Read-o-Matic register can be located up to one-half mile away from the water meter. — Badger Meter Mfg. Co.

Circle No. R-376 on Reader Service Card

Remote Registering Systems

Bulletin P15, Eighth Edition, illustrates and describes Position Motor Type Remote Registering Systems for remote, graphic or visual registration of water levels, gate positions or other moving elements. A variety of self synchronizing motor type transmitters, indicators and recorders are described.—Leupold and Stevens Instruments, Inc.

Circle No. R-377 on Reader Service Card

Reservoir Maintenance and Relining

4-page illustrated brochure describes how leaking reservoirs can be easily restored by relining with reinforced Gunite, economically.—Indiana Gunite & Construction Co.

Circle No. R-378 on Reader Service Card

River Crossing Pipe

Bulletin L115 describes AMERICAN Molox Ball Joint Pipe for river crossings and other submarine services. The catalog contains a detailed description of the joint, various applications and installation methods, dimension and weight tables and assembly instructions. Photographs illustrate types of installations.—American Cast Iron Pipe Company.

Circle No. R-379 on Reader Service Card

Rock Drills, Rotary

Bulletin 87S illustrates and describes the Joy Rotary Percussion Rock Drill. It is rated for holes 1¼" to 1¾" diameter, in materials such as limestone, sandstone, conglomerate and basalt. Designed primarily for underground drilling.—Joy Mfg. Co.

Circle No. R-380 on Reader Service Card

Rotary Distributors

Bulletin No. 5210 describes rotary distributor mechanisms for standard rate and high rate trickling filter applications. Includes application data and specifications.—Ralph B. Carter Co.

Circle No. R-381 on Reader Service Card

Rotary Distributors

Rotoseal Mast type and turntable type rotary distributors for trickling filters are covered in bulletin 23-S-97. In addition to features and details on the Rotoseal machines, the bulletin contains helpful suggestions for trickling filter design.—Walker Process Equipment, Inc.

Circle No. R-382 on Reader Service Card

Rotary Surface Washers

Information available on Rotary Surface Washers specifically designed for rapid sand filters, sizes 2' 8" to 19' 8" diameter. Improves filter operating efficiency and prolongs life. —Simplex Valve and Meter Co.

Circle No. R-383 on Reader Service Card

Rotobelt

The Eimco Rotobelt vacuum filter removes filter medium from drum every filter cycle, for cake discharge and washing of medium. A woven stainless steel flexible medium assists sludge cake removal. — The Eimco Corp.

Circle No. R-384 on Reader Service Card

Sanitary Landfill Methods

Dealing with efficient disposal of refuse which has become as large a problem as good sewage disposal, a 12-page booklet has been issued entitled "Modern Methods and Equipment in Sanitary Landfills." It describes the two types of modern sanitary landfill methods, illustrating them with pictures and diagrams. A step-by-step picture story of a typical sanitary landfill operation in a community of 13,000 is also included to demonstrate this method of efficient refuse disposal.—The Oliver Corp.

Circle No. R-385 on Reader Service Card

Screening Equipment

Booklet 2587 illustrates and discusses Link-Belt's line of screening equipment for water, sewage and industrial waste. Dimension drawings and specifications are included.—Link-Belt Co.

Circle No. R-386 on Reader Service Card

Seals for Flanges

Technical bulletin describing unique Kask-O-Seals for sealing ASA-API flanges. Seals are reuseable, eliminate cleaning or resurfacing of flange faces, do not wear due to pulse or vibration. Seals to 15,000 PSI or high vacuum.—Parker Seal Co., Div. of Parker-Hannifin Corp.

Circle No. R-387 on Reader Service Card

Service Boxes

Catalog and descriptive literature on special and standard boxes available.—Opelika Foundry Co., Inc.

Circle No. R-388 on Reader Service Card

Settling Tanks

An improved settling tank design, the Uniflow, for removal of solids from water, sewage and industrial wastes, is described in detail in new Folder 2648. The text describes advantages of the improved design in

attaining: uniform influent distribution across the tank; uniform flow throughout entire tank length; and, uniform effluent discharge from surface.—Link-Belt Company.

Circle No. R-389 on Reader Service Card

Sewage and Waste Treatment

Bulletin 135A describes in detail Chicago Pump's "Ratedaeration" Sewage Treatment process to serve 20 to 5,000 people.—Chicago Pump.

Circle No. R-390 on Reader Service Card

Sewage and Waste Treatment

Bulletin No. 300 is a general catalog of equipment and methods for modern waste treatment. — Pacific Flush Tank Co.

Circle No. R-391 on Reader Service Card

Sewage Ejectors Pneumatic

Catalog No. KSM-2, a 14 page, 2 color brochure, complete with illustrations, layout diagrams, dimension tables compressor motor selection tables and description of the Komline-Sanderson Pneumatic Sewage Ejector Systems. Covers simplex and duplex and duplex units, pneumatically and electrode controlled.—Komline-Sanderson Engineering Corp.

Circle No. R-392 on Reader Service Card

Sewage Ejectors Pneumatic

This bulletin describes the "Eject-All," a packaged ejector for lifting liquids and solids in suspension. Sizes range from 20 to 600 gpm. Illustrations provide complete details.—Tex-Vit Supply Co.

Circle No. R-393 on Reader Service Card

Sewage Filters, Vacuum

Bulletin No. 108 describes advantages of Komline-Sanderson Coilfilter sewage sludge vacuum filters, with size data.—Komline-Sanderson Eng. Corp.

Circle No. R-394 on Reader Service Card

Sewage Filters, Vacuum

Bulletin No. 109 describes some of the advantages of fresh solids dewatering and gives list of Coilfilter installations. — Komline-Sanderson Eng. Corp.

Circle No. R-395 on Reader Service Card

Sewage Lift Stations

Bulletin 616-B describes the design features and operation of the dependable, factory-built "Du-O-Ject" sewage lift station with exclusive "No-Fail" Electrode System. The "No-Fail" Electrode System eliminates grounding and insulation failures which put conventional ejectors out of operation.—Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-396 on Reader Service Card

Sewage Lift Stations

Complete engineering data manual on factory-built sewage pump stations and a complete line of pneumatic ejector sewage lift stations is available, including specifications, design features, operational characteristics, pump selection charts and other valuable information.—Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-397 on Reader Service Card

Sewage Lift Stations

Exclusive "Way-O-Matic" pneumatic ejector lift station has a superior patented control system to provide maximum dependability and trouble-free operation. Described in Bulletin 610-D which is included in 100-page engineering data manual.—Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-398 on Reader Service Card

Sewage Lift Stations

The operational characteristics and design features of the low-cost, factory-built "Mon-O-Ject" sewage lift station, available with exclusive "No-Fail" Electrode System, is described in Bulletin 615-D, which is included in 100-page engineering data manual.—Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-399 on Reader Service Card

Sewage Lift Stations, Prefabricated

Drawings and Catalog S-55 describing factory-built underground sewage lift stations equipped with pneumatic ejectors.—Blackburn-Smith Mfg. Co., Inc.

Circle No. R-400 on Reader Service Card

Sewage Plant Design Guides

An eight page pamphlet summarizing the basic criteria used by state water pollution control agencies for reviewing sewage treatment plant plans. The basic criteria tabulated is for each of the various treatment units, including screening devices, sedimentation basins, digestors, filters and activated sludge tanks. It also includes a handy tabulation of the water pollution control agencies and their addresses for all states except Alaska and Hawaii.—Portland Cement Assn.

Circle No. R-401 on Reader Service Card

Sewage Sludge Concentrator

4-page folder, describes and illustrates the "Roto-Plug" sewage sludge concentrator. Photos and schematic drawings illustrate operation of equipment. Bulletin RP-100 also gives performance data, sizes, general specifications, space requirements, and special features.—Nichols Engineering & Research Corp.

Circle No. R-402 on Reader Service Card

Sewage Pumps

Vertical close-coupled "Non-Clog" Sewage Pumps by Smith & Loveless are described in Bulletin 500-A with detailed explanation and advantages of mechanical seal system, plus cutaway drawings with identifying call-outs. Described as "the one pump designed to meet all the must requirements for sewage service" and built to the most exacting requirements, the Smith & Loveless sewage pump invites comparison.—Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-403 on Reader Service Card

Sewage Pump Stations

An 8-page bulletin (601-A) in full color on factory-built sewage pump stations includes design features, operation characteristics and details of manufacture. Effective drawings include identifying call-outs of important engineering features. Bulletin included in 100-page engineering data manual.—Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-404 on Reader Service Card

Use Accompanying Reply Card to Obtain Copies of these Bulletins.

Sewage Treatment

A 64-page catalog covering Jeffrey equipment for the treatment of sewage, water and industrial waste. It is profusely illustrated with installation views and line drawings.—The Jeffrey Mfg. Co.

Circle No. R-405 on Reader Service Card

Sewage Treatment

A series of 6 bulletins gives detailed information on equipment to perform various steps in sewage treatment. Collectors for solids removal, screens, grit removal units, rotary distributors and digester sludge heating units are covered.—Walker Process Equipment Inc.

Circle No. R-406 on Reader Service Card

Sewage Treatment Plants

Chicago Pump factory assembled packaged sewage treatment plant for smaller applications serving 10 to 500 people. Odor free, nuisance free, low cost units with capacities of 1,000, 3,000 and 5,000 gpd. Bulletin 136 illustrates and fully describes the unit and its operation.—Chicago Pump.

Circle No. R-407 on Reader Service Card

Sewage Treatment Plants

Bulletin 1200 on factory-built "Oxigest" sewage treatment plant by Smith & Loveless describes design features, operation and installation. Includes color photographs of representative installations, plus simplified explanation of the Aerobic Digestion process.—Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-408 on Reader Service Card

Sewage Treatment Plants

Factory-built and field-erected "Oxigest" sewage treatment plants by Smith & Loveless are described in the complete engineering data manual containing specifications, design drawings, colorful bulletins and notes on sewage treatment. — Smith & Loveless, Div.-Union Tank Car Co.

Circle No. R-409 on Reader Service Card

Sewage Treatment Plants, Compact

Bulletin #7330 describes the design, operation, and installation of a full series of six compact sewage treatment plant for communities of from 100 to 1800 persons, or the population equivalent. — Dorr-Oliver Inc.

Circle No. R-410 on Reader Service Card

Sewage Treatment Tanks

Bulletin T-20, a 2-page bulletin on prestressed concrete tanks for sludge digesters, clarifiers, flocculators, and thickeners.—The Preload Co., Inc.

Circle No. R-411 on Reader Service Card

Sewage, Wastes and Water Treatment Equipment

Bulletin SM-1017 describes and illustrates various equipment items including grit separators, oxidator, clarifiers, chain collectors, rotary distributors, non-clog diffusers and slurry mixers.—The Eimco Corp.

Circle No. R-412 on Reader Service Card

Sewage, Water and Waste Treatment Equipment

Bulletin G-50 gives a brief description and illustrations covering equipment for the sanitary engineering projects. — Walker Process Equipment Inc.

Circle No. R-413 on Reader Service Card

Sewer Cleaning

A fast, economical solution to sewer cleaning and maintenance problems is described in detail by APCO's "Planalyzed Contract Cleaning" brochure. Step-by-step sewer cleaning methods, starting with a free engineering analysis, to the details of the cleaning job, utilizing a wide range of power equipment designed to clean any size or type of pipe from 1½" to 72" in diameter, are outlined.—American Pipe Cleaning Co.

Circle No. R-414 on Reader Service Card

Sewer Cleaning

Illustrated brochure "The Story of Power" describes in detail the sewer cleaning services offered by this company. Among the advantages listed are: speedy results, maximum efficiency, planned programs, full control, public goodwill, and lower costs. —National Power Rodding Corp.

Circle No. R-415 on Reader Service Card

Sewer Line Cleaner

Literature explains how Sanfax 222 chemically burns out tree roots, trash and impediments from sewer lines and drain lines.—Sanfax Corp.

Circle No. R-416 on Reader Service Card

Sewer Lining, Plastic

This bulletin describes T-Lock Amer-Plate, a continuous plastic sewer lining to prevent hydrogen sulfide corrosion. It shows how the T-shaped ribs lock the sheet into the pipe when the concrete is poured.—Amercoat Corp.

Circle No. R-417 on Reader Service Card

Sewer Pipe, Clay

Catalog SE-50 gives a complete summary of shapes and sizes of Natco Clay Sewer Pipe. Catalog VS-30 gives complete information regarding the new Natco "Vitri-Seal" Clay Pipe with compression type joints.—Natco Corp.

Circle No. R-418 on Reader Service Card

Sewer Pipe Coating

4-page bulletin in color describes Rexon® No. 2 Pipe Coating for concrete sewer pipe and other masonry structures subjected to extreme corrosion conditions. It is a synthetic hard rubber which vulcanizes to the masonry surface by catalytic action, and leaves no pin-holes. It is resistant to virtually all acids, alkalies, greases and solvents. — Hamilton Kent Mfg. Co.

Circle No. R-419 on Reader Service Card

Sewer Pipe Gaskets, Rubber

16-page booklet in color describes, illustrates and diagrams 5 different types of Tylox® Gaskets from which a specifically designed cross-section may be selected to provide water-tight compression joints for any type of concrete sewer pipe. Booklet contains full engineering data on Tylox, guides for writing rubber joint specifications, and illustrated installation information.—Hamilton Kent Mfg. Co.

Circle No. R-420 on Reader Service Card

Sewer Pipe Infiltration

Technical information on the use of the Centriseal Process for remotely

stopping infiltration in leaking sewer and storm piping by the use of fast setting plastic grout coupled with closed circuit television for the location and inspection of leaking joints. —Centriline Corp.

Circle No. R-421 on Reader Service Card

Sewer Tools

General Catalog No. 163 lists complete line of sewer tools: root cutters, snake cleaners, sewer and pipe augers, tunneling scoops, sewer rods, sewer flushers, etc., available from this manufacturer.—W. S. Darley & Co.

Circle No. R-422 on Reader Service Card

Sewer Valves

Brochure covering construction and operation of Crispin Sewer Valves designed to eliminate and control air in sewage force mains.—Multiplex Mfg. Co.

Circle No. R-423 on Reader Service Card

Silica (Activated) Feeder

Catalog 60.110 gives description, design features, operating instructions and technical information on the series A-637 WT Silactor, a device for the continuous production and application of chlorine activated silica.—Wallace & Tiernan, Inc.

Circle No. R-424 on Reader Service Card

Silica Feeder, Chlorine Activated

Designed to mix and feed a continuously prepared chlorine activated silica solution, is described in Specification Sheet 70L1400. Sheet discusses the three components of the feeder: F&P Chlorinator, Silica Activator, and Sodium Silicate Metering Pump; and explains operation of equipment.—Fischer & Porter Co.

Circle No. R-425 on Reader Service Card

Single Stage Centrifugal Pumps

This 4-page bulletin discusses the single stage volute pumps for water works, circulation, drainage and general service.—Worthington Corp.

Circle No. R-426 on Reader Service Card

Single Stage Split Case Pump

4 page bulletin No. 1600 describes Type UVBM Vertical Non-clog, Ball bearing Centrifugal Pumps for handling sewage and liquids containing solids.—The Weinman Pump Mfg. Co.

Circle No. R-427 on Reader Service Card

Siphons for Sand Filters

This bulletin provides curves for determining rates of siphons discharging into open troughs. Sand filter design for smaller plants is discussed along with piping layouts for the types of siphons available.—Pacific Flush Tank Co.

Circle No. R-428 on Reader Service Card

Sleeves and Valves, Cutting-In

It is easy to install more valves on existing pipe lines, for better control, by using these Mechanical Joint Cutting-In Sleeves and Valves. Suggestions on how to install. Circular No. 20.—M&H Valve and Fittings Co.

Circle No. R-429 on Reader Service Card

Sludge Collectors

Bulletin 315-61 presents the features and benefits of the complete line of REX Conveyor Sludge Collectors and appurtenances. Bulletin 315-62 discusses the important components of the REX M.E. Sludge Collector, a light duty unit suitable for clarifying water in a small plant. Bulletin 315-64 describes the components used in the REX MI Sludge Collector, also a unit designed for the small plant. Bulletin 315-6A1 presents the features of the new REX Circular Scraper Sludge Collector and Scum Remover designed specifically for the "round tank" market.—Chain Belt Co.

Circle No. R-430 on Reader Service Card

Sludge Collectors

Descriptive bulletin showing self-propelled traveling bridge type sludge scraper for rectangular settling tanks; unit has no moving maintenance parts immersed in sewage.—Komline-Sanderson Engr. Corp.

Circle No. R-431 on Reader Service Card

Sludge Collectors

Book 2546 presents the complete line of six series and 15 types of Circuline collectors available for water, sewage and industrial waste treatment settling tanks. The new 28-page book announces two new series and six new types of collectors.—Link-Belt Company.

Circle No. R-432 on Reader Service Card

Sludge Collectors

Various circular collector designs are discussed and illustrated in bulletin 9-W-65. Includes types for small diameter, light-duty application to powerful, heavy duty large diameter units. Covers design features and special applications. — Walker Process Equipment Inc.

Circle No. R-433 on Reader Service Card

Sludge Collectors, Straightline

A new 28-page Book 2746, "Straightline Sludge Collectors," is now available from Link-Belt describing the company's complete line of sludge collectors for rectangular settling tanks. New data in this publication enables selection of the proper size tank for both the type "H" and type "L" sludge collectors. New mechanical details and arrangement drawings of various designs for both collectors are illustrated and described. The "Ten States Standards for Sewage Works" specifications for sedimentation tanks are reprinted in their entirety in Book 2746.—Link-Belt Co.

Circle No. R-434 on Reader Service Card

Sludge Concentrators

Bulletin R.P. 100 describes the Roto-Plug Sludge Concentrator for dewatering sewage sludge without the use of chemicals.—Nichols Eng. & Research Corp.

Circle No. R-435 on Reader Service Card

Sludge Digesters

Two types, a semi-dome roof for large plants and an I-beam roof for small plants, both with scum breakers and sludge concentration, are described in an eight-page catalog.—Yeomans Brothers Co.

Circle No. R-436 on Reader Service Card

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Sludge Digestion

In addition to bulletins 332 and 235 on floating covers and sludge heat exchangers, P. F. T. has available bulletins 236 and 137 covering floating cover position indicators and gauge boards.—Pacific Flush Tank Co.

Circle No. R-437 on Reader Service Card

Sludge Disintegrator

Literature describes the increasing popularity of sewage sludge as a soil conditioner.—Royer Foundry & Machine Co.

Circle No. R-438 on Reader Service Card

Sludge Disposal

Complete sludge disposal process for small communities from 3,000 to 10,000 population described in Bulletin 245. Converts settled sludge to sterile ash simply and economically. —Nichols Engineering & Research Corp.

Circle No. R-439 on Reader Service Card

Sludge Drying and Incineration

Bulletin FD-57 covers the C-E Raymond System of Sludge Drying and Incineration. It briefly outlines the problem of sewage disposal and shows why heat drying is regarded as an ideal solution. Diagrams and photographs are also included.—Combustion Engineering Inc.

Circle No. R-440 on Reader Service Card

Sludge Flowmeter

Specification Sheet 10D1416C describes this special magnetic flowmeter for continuous metering of sewage sludge. Sheet also outlines features of transistorized indicators and recorders designed to receive measurement signals from the meters. Sheet includes specifications and meter dimension drawings.—Fischer & Porter Co.

Circle No. R-441 on Reader Service Card

Sludge Furnaces

Bulletin 238 provides design and operating information on the Nichols Herreshoff Multiple Hearth Furnace for burning or drying sewage sludge, and burning screenings, grit and grease. Performance data on existing installations available.—Nichols Engineering & Research Corp.

Circle No. R-442 on Reader Service Card

Sludge Heaters

Bulletin 1001 describes construction features and performance data on sludge heaters and heat exchangers of the forced counter flow type.—Ralph B. Carter Co.

Circle No. R-443 on Reader Service Card

Sludge Heaters

Heatx, digester sludge heat exchangers are presented in bulletin 24-S-82. Includes complete description, application details and specifications. —Walker Process Equipment Inc.

Circle No. R-444 on Reader Service Card

Sludge Readers, Nuclear

Bulletin No. KSM-7, a description of the Komline-Sanderson nuclear sludge reader, automatic pumping control. Utilizes a harmless nuclear energy source. Shows suggested control layouts. — Komline-Sanderson Eng. Corp.

Circle No. R-445 on Reader Service Card

Sludge Removal

REX Unitube Tow-Bro for efficient removal of light, tricky sludge with minimum agitation is described in Bulletin 315-81.—Chain Belt Co.

Circle No. R-446 on Reader Service Card

Slurry Feeder

This catalog briefly describes the design, operation and application of this positive displacement slurry pump for feeding lime, diatomaceous earth and similar slurries.—Precision Chemical Pump Corp.

Circle No. R-447 on Reader Service Card

Softeners

Bulletin 5763-A covers zeolite softeners built by General Filter Co. Included are facts on hardness, design, and construction notes, charts and method for selecting softeners. Various types of piping, valving and control are described.—General Filter Co.

Circle No. R-448 on Reader Service Card

Squirrel-Cage Motors

This bulletin describes the company's large two-hole squirrel-cage induction motors, 900 hp and larger, designed to meet requirements of today's high speed drives.—Allis-Chalmers Mfg. Co.

Circle No. R-449 on Reader Service Card

Standard Sewage Siphons

This bulletin describes the P.F.T. standard sewage siphon for small disposal plants for use with small sand filters, sub-surface tile fields and either septic tanks or small Imhoff tanks. Standard dimensions and capacity of siphons are included.—Pacific Flush Tank Co.

Circle No. R-550 on Reader Service Card

Steel Pipe

Five booklet describe the fabrication and installation of interesting steel water lines in a number of diameters. Booklet 503 describes a 14-ft flow line; Booklet 397 describes a 96-in. industrial water line; Booklet 402 describes the 72-in. Ramapo force main in New Jersey; Booklet 431 describes 42-in. pipe at Lancaster, Pa.; and Booklet 408 describes a 36-in. and 30-in. pumping main at Reading, Pa.—Bethlehem Steel Co., Inc.

Circle No. R-551 on Reader Service Card

Steel Pipe

Booklet 584 "Building St. Paul's Big Steel Conduits." Describing installation of all-welded 60-in. and 90-in. supply lines. Also ask for literature describing Bethlehem's new bell-and-spigot pipe with rubber gaskets for fast, economical, leakproof joints. —Bethlehem Steel Co.

Circle No. R-552 on Reader Service Card

Steel Pipe

Booklet 588 "60 Years of Steel Water Mains" is a survey of the long service life of large-diameter steel mains, many of which were installed before the turn of the Century. All facts stated are certified accurate by waterworks officials. — Bethlehem Steel Co.

Circle No. R-553 on Reader Service Card

Use Accompanying Reply Card to Obtain Copies of these Bulletins.

Steel Reservoirs and Standpipes

A 20-page bulletin on Horton Steel Reservoirs and Standpipes. Illustrations show installations from 150,000 to 6,000,000 gal. capacity with cone, umbrella, or ellipsoidal roofs and ornamental structures with special architectural features. Also included are: table of standard capacities, information on foundation, advantage of pickling and paintings, and data on the use of suction tank for fire protection.—Chicago Bridge & Iron Co.

Circle No. R-554 on Reader Service Card

Storage Bins

Bulletin Seg-13 contains details and illustrations on circular storage bins of Natco Segmentile, which are adaptable for sand, ash and coal bins, as well as other types of bulk storage. —Natco Corp.

Circle No. R-555 on Reader Service Card

Strainers

For intake and suction lines, in sizes up to 40" with slots ¼", and smaller, strainers furnished with flanged or screwed connections for vertical or horizontal installation, Catalog No. 1252A. — Cook Well Strainer Co.

Circle No. R-556 on Reader Service Card

Strainers

For sea water installation, Catalog No. 1252-A illustrates this strainer for vertical or horizontal installation for supplying inland pools. — Cook Well Strainer Co.

Circle No. R-557 on Reader Service Card

Strainers, Liquid

Automatic self-cleaning strainers are described in detail in Catalog S-107.—Blackburn-Smith Mfg. Co.

Circle No. R-458 on Reader Service Card

Strainers, Rotary MultiDuct, Liquid

Special design strainer permits long periods of operation between cleanings. Design allows strainer to be cleaned without interruption of service. Bulletin available. — Blackburn-Smith Mfg. Co.

Circle No. R-459 on Reader Service Card

Summators

A simplified description of the method of summating pneumatically a series of separate flow variables is given in Technical Bulletin 752. The Simplex Type PM Pneumatic Summator is a rugged but reliable method of obtaining total flow rates from many sources. — Simplex Valve & Meter Co.

Circle No. R-460 on Reader Service Card

Supervisory Control

Bulletin 2-1.20-1 discusses the Laboratory Control concept in water filtration and treatment, featuring finger tip control over plant throughout, chemical additions and filter backwash from a single console in the laboratory. — Builders-Providence Div., B-I-F Industries.

Circle No. R-461 on Reader Service Card

Supervisory Remote Control

The Bulletin SC outlines the method of pump or valve control over one pair of wires any distance. It also contains information on report back using the same pair of wires.—Healy-Ruff Company.

Circle No. R-462 on Reader Service Card

Surface Washers

4-page Bulletin fully describes the complete line of Rotary self-powered Surface Washers. This bulletin contains installation drawings, sizing information, unit dimensions, as well as operating and maintenance instructions.—F. B. Leopold Co., Inc.

Circle No. R-463 on Reader Service Card

Surge & Water Hammer Control

A 28 page booklet describing the construction of Crispin automatic air valves available for control of air problems in lines handling liquids.—Multiplex Mfg. Co.

Circle No. R-464 on Reader Service Card

Surge and Water Hammer Control

Bulletin 1225 describes Type CCAV Controlled closing valves explaining how shock effects of water hammer are dissipated. — Simplex Valve and Meter Co.

Circle No. R-465 on Reader Service Card

Swimming Pool Filters

New data manual on quality S & L filtration equipment for swimming pools. Contains diagrams, selection charts and lists of installations.—Smith & Loveless Div.—Union Tank Car Company.

Circle No. R-466 on Reader Service Card

Swimming Pool Operation and Disinfection

(Bulletin P-1009)—describes general operations, filtration and sterilization methods for commercial pools. Penn-salt Chemicals Corp., Industrial Chemicals (West).

Circle No. R-467 on Reader Service Card

Synchronous Generators

Publication 2100-PRD-250 describes a line of alternating current generators in ratings from 3.75 through 62.5 kva. These machines are "non-packages," without voltage regulators. Speeds available are 1000-1800 rpm. All standard voltages and combinations of standard voltages are available. Suitable for operation at either 60 or 50 cycles.—Electric Machinery Mfg. Co.

Circle No. R-468 on Reader Service Card

Synchronous Motors

Bulletin 1100-PRD-253 describes a line of heavy duty, synchronous motors in rating of 600 hp and up. They feature a husky, steel frame, heavy shafts, oil pressure type, sleeve bearings with quick view sight gages and high capacity starting windings. Speeds from 500-1800 rpm, at 0.8 or 1.0 power factor, 60-50 cycles and at all standard voltages.—Electric Machinery Mfg. Co.

Circle No. R-469 on Reader Service Card

Synchronous Motors, Vertical

Publication 1100-PRD-247 describes a line of vertical synchronous motors from 250 hp and up. The motor line is particularly suited for vertical pump drive. Available in either hollow or solid shaft construction at speeds of 1100 rpm and lower at all standard voltages.—Electric Machinery Mfg. Co.

Circle No. R-470 on Reader Service Card

Use Accompanying Reply Card to Obtain Copies of these Bulletins.

Tank Liner

Literature available describing the company's non-toxic tank liner. Also available are literature pieces explaining its complete maintenance service and for elevated water storage tanks, standpipes, and reservoirs. — Speelmon Elevated Tank Service.

Circle No. R-471 on Reader Service Card

Tapping Machines

Bulletin T-54 illustrates and describes the Smith T-54 Tapping machine which is used in connection with Tapping Sleeves, Hat Flanges, Saddles and Tapping Valves to make 2″ through 12″ connections under pressure to Cast Iron, Cement Asbestos, Steel and reinforced concrete pressure pipe.—A. P. Smith Manufacturing Co.

Circle No. R-472 on Reader Service Card

Tapping Machines, Pipe

Folder illustrates and describes the all-new, hand or power-operated Mueller B-100 Drilling, Tapping and Inserting Machine, which is based on proven "double pressure chamber" principle. All major features are shown in large two-color cut-aways. Also illustrated are revolutionary new Air and Electric Power Operators developed to give automatic feed for faster taps and longer tool life.—Mueller Co.

Circle No. R-473 on Reader Service Card

Tapping Sleeves

Circular #12 illustrates a complete line of tapping sleeves and tapping valves either with hub or mechanical joint ends.—M&H Valve and Fittings Co.

Circle No. R-474 on Reader Service Card

Tapping Sleeves

Bulletin MJ-1 describes and illustrates the complete line of mechanical joint tapping sleeves and valves manufactured by the company.—A. P. Smith Mfg. Co.

Circle No. R-475 on Reader Service Card

Taste and Odor Control

8-page illustrated brochure describes Carox (T.M.) Potassium Permanganate technique for removing tastes and odors, includes full instruction for evaluation of water for permangante demand. — Carus Chemical Co., Inc.

Circle No. R-476 on Reader Service Card

Taste and Odor Control

Published case history reports describe actual water department experiences using potassium permanganate for taste and odor control.—Carus Chemical Co., Inc.

Circle No. R-477 on Reader Service Card

Telemetering

8-page Bulletin 230.20-2 on Chronoflo® Telemetering equipment and systems. Bulletin gives the basics of transmitter and receiver operation in a time-duration impulse system. A brief description of differential producers and a listing of applications are also included. — Builders-Providence Div., B-I-F Industries.

Circle No. R-478 on Reader Service Card

Telemetering

Bulletin B56 describes an all-electronic telemetering system of totally new design, offering high scanning speed and greater sensitivity to rapidly fluctuating measurements. The transmitter features a photo-diode detector which scans input position in relation to a cam etched on glass. There is no contact, hence no friction, between input arm and cam. System has few moving parts, requires little maintenance.—The Foxboro Co.

Circle No. R-479 on Reader Service Card

Television for Pipeline Inspection

Information available on a complete television system for the inspection of sewers, water lines, conduit wells, water tanks, etc. The system is capable of being pulled through pipelines as small as 4 in. in diameter and as large as 48 in. in diameter.—Inspectoline Inc.

Circle No. R-480 on Reader Service Card

T-Lock-Amer-Plate

This brochure describes T-Lock Amer-Plate, a continuous plastic sewer lining. "T-Lock" refers to the T-shaped ribs which project from the back of the sheet and lock the sheet into the pipe or structure when the concrete is cast.—Amercoat Corp.

Circle No. R-481 on Reader Service Card

TV Pipe Inspection

Inspection of underground pipes by closed circuit television, eliminating guesswork by pinpointing exact location of countless trouble spots, is explained in brochure. Details of fast and economical "Monitored TV Pipe Inspection" process by APCO, used to inspect pipe interiors 6 in. in diameter and larger, including municipal sanitary and storm sewers, water pipes and wells, boiler tubes and others, are presented in reference literature.—American Pipe Cleaning Co.

Circle No. R-482 on Reader Service Card

Thickeners

The REX Float Treat system of separators and thickeners is a process which removes suspended organic matter and usual chemical flocs by flotation using dissolved air. This exclusive REX feature is presented in Bulletin 315-101.—Chain Belt Co.

Circle No. R-483 on Reader Service Card

Thickeners

Eimco-Process Thickeners are built in several basic types and available with a number of custom adaptations for special sedimentation problems. Bulletin SM-1004.—The Eimco Corp.

Circle No. R-484 on Reader Service Card

Trash Racks

Bull. 02B9207 describes the Leonard Trash Rack Rakes with dimensions, specifications and typical arrangements. — Allis-Chalmers Mfg. Co.

Circle No. R-485 on Reader Service Card

Trench Braces

SIMPLEX Drop-forged Steel Trench Braces are fully described in Bulletin Industrial-61. — Templeton, Kelly & Co.

Circle No. R-486 on Reader Service Card

Trenchers and Backfillers

A 2-color booklet describing the features and listing specifications of the models 92 and 95 "Baby Diggers," the models 10, 140, 240, and 320

standard trenchers, and models 80W and 190 backfillers. Photographs of each piece of equipment are shown along with illustrations of the equipment in operation. — Cleveland Trencher Co.

Circle No. R-487 on Reader Service Card

Trenching & Construction Equipment

Thirteen bulletins on tractors, crawlers, trenchers and loaders for installation of water mains or sewers. —The Oliver Corp.

Circle No. R-488 on Reader Service Card

Trickling Filter Distributors

Technical bulletin describes reaction and positive drive types, equipped with patented oil seal which will withstand at least 10 ft of water pressures. Also bulletin on "Multi-Flo" self-adjusting flow distribution Nozzle for wide-range flows in reaction-drive rotary distributors. —American Well Works.

Circle No. R-489 on Reader Service Card

Trickling Filter Distributors

Bulletin #116, 24-pages on the theory, operating results, and design data necessary to design and specify the high capacity Lakeside Aero-filter.—Lakeside Engineering Corp.

Circle No. R-490 on Reader Service Card

Trickling Filter Distributors

Bulletin 313A covers spreader jets for rotary distributors for trickling filters.—Pacific Flush Tank Co.

Circle No. R-491 on Reader Service Card

Trickling Filter Distributors

This bulletin describes the "Sy-No-Seal" reaction type rotary distributor which contains no seal between the stationary center column and the rotating distribution arms.—Smith & Loveless, Div.—Union Tank Car Company.

Circle No. R-492 on Reader Service Card

Trickling Filter Process

The Spirahoff combination clarifier-digester is a complete sewage treatment plant for primary treatment or a principle component of a secondary treatment system. Described in detail including recommended sizes and specifications in a 24-page engineers' manual. — Yeomans Brothers Co.

Circle No. R-493 on Reader Service Card

Tyton Joint® Pipe

This booklet presents the U. S. centrifugally cast iron TYTON JOINT pipe for water and sewage. This new joint is simple, sturdy, and tight. Illustrations show details of joint and method of assembly.—U. S. Pipe & Foundry Co.

Circle No. R-494 on Reader Service Card

Vacuum Breakers

Brochure on Crispin air and vacuum valves designed to break the vacuum during the emptying operation of a pipe line or tank.—Multiplex Mfg. Co.

Circle No. R-495 on Reader Service Card

Vacuum Breaking Valve

Bulletin 1200 describes the type VAC Air Inlet (Vacuum Breaking Valve) for both water and sewage lines. Complete with dimensions and capacities. Bulletin describes new design additions and frost proof installation directions.—Simplex Valve and Meter Co.

Circle No. R-496 on Reader Service Card

Vacuum Filters

Bulletin 1860.20-2 on Vacuum Filters for economical and efficient filtration of swimming pool and industrial process water.—Builders-Providence Div., B-I-F Industries.

Circle No. R-497 on Reader Service Card

Vacuum Filters

16 page brochure on the Coil-filter, the sludge vacuum filter featuring permanent type filter media, non-clogging operation, constant output. Standard sizes of equipment are listed. Bulletin No. 106.—Komline Sanderson Engineering Corp.

Circle No. R-498 on Reader Service Card

Valve Actuator Conversion Units

Bulletin V-200 includes diagrams showing how manually operated valves may be converted to automatic operation without disturbing valve or piping.—C. H. Wheeler Mfg. Co.

Circle No. R-499 on Reader Service Card

Valves, Air Release

A 28 page catalog offering complete information on the many types of Crispin automatic air valves preferred by works engineers for over 45 years for positive air control.—Multiplex Mfg. Co.

Circle No. R-500 on Reader Service Card

Valves-Ball

The newest type of Ball Valve utilizing a rubber seat for bubble-tight closure and ease of operation. Completely described, with drawings and specification information in bulletin BV-1B.—Henry Pratt Co.

Circle No. R-501 on Reader Service Card

Valve Boxes

Descriptive literature and catalog available.—Opelika Foundry Co., Inc.

Circle No. R-502 on Reader Service Card

Valves, Butterfly

Bulletins 650.20-1 and 650.20-2 on tight-closing, rubber seated butterfly valves built to AWWA specifications. —Builders-Providence Div., B-I-F Industries.

Circle No. R-503 on Reader Service Card

Valves, Butterfly

Bulletin No. 5708 gives complete description of the Darling-Pelton Rubber Seated Butterfly Valves.—Darling Valve & Mfg. Co.

Circle No. R-504 on Reader Service Card

Valves, Butterfly

This 2-color brochure describes Leopold rubber seated butterfly valves. Complete details on the construction features and valve assembly are included.—F. B. Leopold Co., Inc.

Circle No. R-505 on Reader Service Card

Valves, Butterfly

Complete information on full line of AWWA rubber seat butterfly valves by originator of this type equipment. Bulletin B-2B includes data on valve sizing, operator selection, theory of valve design and all information pertinent to the specification of butterfly valves.—Henry Pratt Company.

Circle No. R-506 on Reader Service Card

Valves-Butterfly-Wafer Type

A new engineering Bulletin B-10B

containing the most up-to-date butterfly valve information and describing the new rubber seat wafer type butterfly valve. Bulletin contains all information needed to order or specify —including price list.—Henry Pratt Company.

Circle No. R-507 on Reader Service Card

Valves, Check

Circular #18 illustrates and describes a complete line of swing check valves in sizes up to 24", available with outside lever and weight or outside spring and lever arrangement. Can be supplied with flanged or mechanical joint ends. This line features full-way openings in all sizes. —M&H Valve and Fittings Co.

Circle No. R-508 on Reader Service Card

Valves, Cone

Bulletin No. 2 describes in detail Willamette Cone Valve design materials and suitability for water and sewage works applications.—Willamette Iron and Steel Co.

Circle No. R-509 on Reader Service Card

Valve Controls, Electrodyne

Bulletin 809 on Type MN1, side mounted, for small gates, globes, plugs, dampers, etc.; Bulletin 810 on Type B-2, side mounted, position seating for plug valves and Bulletin 817 on Type TN-Y, top mounted, thrust seating, with yoke in unit, for gate and globe valves.—Hupp Aviation Div., Hupp Corp.

Circle No. R-510 on Reader Service Card

Valves, Diaphragm

8-page Bulletin gives complete information on the Grinnell-Saunders diaphragm valve.—Grinnell Co., Inc.

Circle No. R-511 on Reader Service Card

Valves, Eccentric

This new Bulletin #110 contains sizes, dimensions and materials of DeZurik eccentric valves. Gives information on handling clear liquids, sludges, slurries and chemicals. Explains complete line of eccentric valves and accessories, discussing eccentric action and other exclusive DeZurik features.—DeZurik Corp.

Circle No. R-512 on Reader Service Card

Valves, Electric Check

Bulletin W-10A describes the G-A double-cushioned Electric Check Valve which does not open until the pump comes up to speed. Closing of the valve begins while pump is still operating, and when valve is 95% closed the pump is automatically shut down.—Golden-Anderson Valve Specialty Co.

Circle No. R-513 on Reader Service Card

Valves, Filter Control

20-page Bulletin #150 explains eccentric action, gives dimensions, materials and accessories of DeZurik valves. Illustrates valves for filter control and pump check applications. Includes information on both throttling and on-off eccentric valves, with pneumatic, hydraulic, and electric actuation.—DeZurik Corp.

Circle No. R-514 on Reader Service Card

Valves for Concrete Pipe

8-page circular (illustrated) describing valves with special hubs for installation in concrete pipe lines without use of adapters, employing standard concrete pipe joint design and materials. Circular 26.—M&H Valve and Fittings Co.

Circle No. R-515 on Reader Service Card

Valves, Gate, AWWA

Literature describing "R. D. Wood" valves; double disc, taper seat, non-rising stem or OS&Y; hub, mechanical joint or flanged ends; "O"-ring seal design.—R. D. Wood Co.

Circle No. R-516 on Reader Service Card

Valves, Howell-Bunger

16 page bulletin 02B9206 tells how these valves operate for the easy regulation and control of water under free discharge for high and low heads. —Allis-Chalmers Mfg. Co.

Circle No. R-517 on Reader Service Card

Valves, Knife Gate

New 8-page bulletin 302 illustrates and describes DeZurik's metal to metal and rubber seated knife gate valves. It lists the styles, materials, actuators and accessories. Typical applications include: slurries, dry solids, crystalline and caking sludges. Actuators available are: the standard handwheel, lever, bevel gear and pneumatic and hydraulic actuation for on-off or positioning control.—DeZurik Corp.

Circle No. R-518 on Reader Service Card

Valves, Low Pressure

Circular #16 describes a full range of low pressure gate valves available in either double disc or solid wedge design and for 50# or 100# water working pressure. Size range 10" to 42".—M&H Valve and Fittings Co.

Circle No. R-519 on Reader Service Card

Valve Operators, Hydraulic

Literature describes this manufacturer's line of hydraulic valve operators (truck-mounted) that provide fast, safe control of 10 in. to 60 in. valves.—Payne Dean & Co.

Circle No. R-520 on Reader Service Card

Valves, Plug

Literature describes plug valve with a facing of Hycar American Rubber. —DeZurik Corp.

Circle No. R-521 on Reader Service Card

Valves, Plug

Bulletin #110 contains a complete line of plug valves & accessories, discussing eccentric action and other exclusive features of DeZurik valves. Sizes, materials and dimensions are included.—DeZurik Corp.

Circle No. R-522 on Reader Service Card

Valves, Plug

Folder describes the new ORI-SEAL Valve. This maintenance free valve is permanently lubricated and is easy turning in large sizes even after long periods of use.—Mueller Co.

Circle No. R-523 on Reader Service Card

Valve Position Indicators

Potentiometric or target type valve position indicators are ilustrated in Bulletin 1006. Bulletin shows method of mounting on standard Simplex consoles.—Simplex Vave and Meter Co.

Circle No. R-524 on Reader Service Card

Valves, Sewage and Waste

Solid wedge gate valves, Class A,

B, and C, maximum flow efficiency with valve operation unhampered by accumulated solids or silt. Circular No. 24.—M & H Valve & Fittings Co.

Circle No. R-525 on Reader Service Card

Valves, Sewage Surge Relief

Bulletin SEW-1 describes the G-A Sewage Surge Relief Valve designed to prevent damage from overpressure in sewage lines. This valve opens immediately and automatically when the line pressure exceeds a predetermined setting. — Golden-Anderson Valve Specialty Co.

Circle No. R-526 on Reader Service Card

Valves, Surge Arrestor

New 16-page Bulletin W-16 describes the Golden-Anderson Cushioned Surge Arrestor Valve that anticipates the surge to protect the system. Pilot controls automatically open main valve on abnormal pressures, subnormal pressures or electrical power failure.—Golden-Anderson Valve Specialty Co.

Circle No. R-527 on Reader Service Card

Valves, Surge Relief

Bulletin W-2A describes G-A Cushioned Surge Relief Valves in sizes ½" to 36". These valves are used to protect water lines against excessive pressures caused by surges in the system — Golden-Anderson Valve Specialty Co.

Circle No. R-528 on Reader Service Card

Valves, Water Works

Bulletin No. WW-58 gives complete information on many types of curb stops, corporation stops, gooseneck meter stops, service boxes and couplings that are popular in the water works industry.—A. Y. McDonald Mfg. Co.

Circle No. R-529 on Reader Service Card

Valves, Water Works

Literature available illustrates and describes this manufacturer's extensive line of waterworks valves.—Chapman Valve Mfg. Co., a subsidiary of Crane Co.

Circle No. R-530 on Reader Service Card

Venturi Tubes

A condensed description of many of the types of Venturi Tubes made by Simplex Valve and Meter Company may be found in Technical Bulletins No. 100, 104, 105, 106. These bulletins outline the services for which each type is designed and will serve as a reliable reference for the designing water or sewage works engineer. —Simplex Valve & Meter Co.

Circle No. R-531 on Reader Service Card

Vertical Turbine Pumps

Bulletin No. 1100 illustrates and describes this manufacturer's advanced "Verti-Line" Pumps built to standards far beyond those used for conventional vertical turbine pumps. —Layne & Bowler Pump Co.

Circle No. R-532 on Reader Service Card

Vertical Turbine Pumps

This bulletin diagrammed in color, discusses water lubricated vertical turbine pumps in capacities of from 15 to 15,000 GPM. — Worthington Corp.

Circle No. R-533 on Reader Service Card

Vibration Isolators

8-page brochure in color fully describes, illustrates and diagrams Rex-on® Self-Leveling Vibration Mounts for isolating vibration and deadening the sound of operating machinery. Mounts use rubber or neoprene elements to float the load "in shear" and are so designed that accidental overloading does them no damage. Booklet includes easy-to-use tables for calculating Mounts needed, and installation drawings and instructions. — Hamilton Kent Mfg. Co.

Circle No. R-534 on Reader Service Card

Vitrified Clay Pipe

Bulletin PS-101 is a 4-page folder in color which describes Presto-Seal, a vastly improved vitrified clay pipe with patented spigots and sockets of air-cured polyester resin with a flexible rubber compression seal. Kaul Clay Company.

Circle No. R-535 on Reader Service Card

Waterproofing

24-page specification guide for the Thoro System of waterproofing, protective and corrective treatments for masonry—concrete, block, stucco, tile, stone.—Standard Dry Wall Products, Inc.

Circle No. R-536 on Reader Service Card

Water and Sewage Valves

A 28 page catalog offering complete information on the many types of Crispin air valves for positive air control on water and sewage lines.—Multiplex Mfg. Co.

Circle No. R-537 on Reader Service Card

Water and Waste Treatment Equipment

Buyer's Guide 1010 for Permutit Water and Waste Treatment Equipment covers Aerators, Degasifiers, Deaerators, Precipitators, Chemical Feeders, Gravity and Pressure Filters, Softeners, Demineralizers, Ion Exchangers, Meters and Controls. Lists equipment size ranges and tables, includes request designations for all major equipment catalogs.—The Permutit Co., a division of Pfaudler Permutit Inc.

Circle No. R-538 on Reader Service Card

Water and Waste Water Treatment

Bulletin No. 1010. General Bulletin of equipment covering details and advantages to perform various functions in sewage, waste and water treatment plants.—Ralph B. Carter Co.

Circle No. R-539 on Reader Service Card

Water Clarification

Hagan Coagulant Aids Nos. 7, 11 and 18, used to improve floc formation in clarifying and softening municipal, industrial and oil field water systems, are described. — Hagan Chemical & Controls, Inc.

Circle No. R-540 on Reader Service Card

Water Level Recorder

Bulletin 24, Tenth Edition contains eight pages of illustrations and decriptive data on the Stevens Type F water Level Recorder. Applications data for this extremely sensitive and accurate, yet inexpensive recorder, is included.—Leupold and Stevens Instruments, Inc.

Circle No. R-541 on Reader Service Card

Use Accompanying Reply Card to Obtain Copies of these Bulletins.

Water Mains Restored

The story of clogged and abandoned water mains returned to normal use after patented cleaning process applied. New brochure describes patented equipment used to restore water pipes to a guaranteed 95% of normal capacity, at a fraction of the cost of new pipe installation.—National Power Rodding Corp.

Circle No. R-542 on Reader Service Card

Water Meters

Bulletin 380-20-2 describes the Propeloflo Meter, a propeller type, totalizing flow meter designed for metering water and other liquids in water works and chemical or process industries.—Builders-Providence Div., B-I-F Industries

Circle No. R-543 on Reader Service Card

Water Pipe Cleaning

APCO's exclusive "Planalyzed Contract Cleaning" service, offering a fast, economical solution to low water pressures, discolored water, corrosion and all other types of water pipe problems, is outlined in brochure. Utilizing a wide range of special design power equipment and skilled, efficient crews, APCO provides a complete service, beginning with a free estimate and thorough investigation to the handling of every detail of the water pipe cleaning operation. — American Pipe Cleaning Co.

Circle No. R-544 on Reader Service Card

Water Screens

The complete line of REX self-cleaning Traveling Water Screens of 2 ft to 10 ft width are described in Bulletin #54-83.—Chain Belt Co.

Circle No. R-545 on Reader Service Card

Water Seal Units

Section 1870 of Pacific Pumping Co.'s general catalog lists and describes Water Seal Units for maintaining clean water pressure supply to the packing glands of sewage or other pumps handling liquids containing dirt or abrasives; or to water cooling jackets of hot liquid pumps.—Pacific Pumping Co.

Circle No. R-546 on Reader Service Card

Water, Sewage and Industrial Waste Treatment Equipment

Book 2617 presents the complete sanitary engineering equipment line. The new 20-page book contains illustrations and photographs of the latest sanitary engineering equipment and also shows flow diagrams of how this equipment can be installed in typical water, sewage and industrial waste treatment plants.—Link-Belt Co.

Circle No. R-547 on Reader Service Card

Water, Sewage and Trade Waste Treatment Equipment

Bulletin No. 35-D is a comprehensive catalog which covers design details, specifications and applications of Hardinge Circular and Rectangular Clarifiers, Digesters, Sand Filters, applied to municipal sewage treatment, muncipal and industrial water treatment and industrial liquid waste treatment.—The Hardinge Co., Inc.

Circle No. R-548 on Reader Service Card

Water, Sewage and Trade Waste Treatment Installations

Bulletin AH-442. A four-page brochure which shows four color installation photos of various Hardinge installations, including Clarifiers, Thickeners and Sand Filters applied to industrial and municipal water and waste treatment.—The Hardinge Co., Inc.

Circle No. R-549 on Reader Service Card

Water Storage Tanks

Bulletin T-22, 4-page booklet provides general information on prestressed concrete water storage tanks. T-19, an 8-page technical booklet on the design of prestressed concrete tanks for water supply.—The Preload Co., Inc.

Circle No. R-550 on Reader Service Card

Water Storage Tanks, Steel

"Steel Tanks Store Water Best" is an attractive, 8-page brochure containing many excellent photographs of a variety of different types of elevated tanks, standpipes and reservoirs constructed of steel in various parts of the country.—Steel Plate Fabricators Association.

Circle No. R-551 on Reader Service Card

Water Treatment

8-page illustrated brochure discusses taste and odor control, iron and manganese removal utilizing the Carox (T.M.) Potassium Permanganate treatment technique. Includes full instructions for evaluation and use.—Carus Chemical Co., Inc.

Circle No. R-552 on Reader Service Card

Water Treatment

A 24-page illustrated booklet describing water treatment services offered by Hall Laboratories. Included is a bibliography of technical papers authored by Hall personnel. — Hall Laboratories, division of Hagan Chemicals & Controls, Inc.

Circle No. R-553 on Reader Service Card

Water Treatment

Process Bulletin C2 describes Nalco Method for Treatment of Recirculating Cooling Water and Process Water Systems. — Nalco Chemical Company.

Circle No. R-554 on Reader Service Card

Water Treatment

Reference folder serves as a file on activated silica sol used as coagulant aid for treating raw, process and waste waters. Advantages are cited pertinent to improved quality of filter water. Sodium silicate control of corrosion in water lines is reviewed, with a list of metals protected.—Philadelphia Quartz Co.

Circle No. R-555 on Reader Service Card

Water Treatment Chemicals

Product bulletin describes effectiveness of chemical treatment of water mains to retard corrosion with prescribed dosages and methods.—American Pipe Cleaning Co.

Circle No. R-556 on Reader Service Card

Water Treatment Chemicals

Product Bulletins describe chromates and polyphosphates for prevention of scale and corrosion and microbiological control. — Nalco Chemical Co.

Circle No. R-557 on Reader Service Card

Water Treatment Equipment

For efficient, economical pre-treatment of water prior to filtration, REX

Chain Belt has the equipment that assures the utmost depenable operation and performance. The complete line of flocculators, clarifiers and sludge removal equipment for water treatment plants is described in Bulletin 315-12.—Chain Belt Co.

Circle No. R-558 on Reader Service Card

Water Treatment Equipment

Flash mixers and contactors, clarifiers, reactor-clarifiers, flocculation mechanisms, feeders and other equipment are described in new Bulletin SM-1013.—The Eimco Corp.

Circle No. R-559 on Reader Service Card

Water Treatment Equipment

A new booklet (4433) describes modern water treatment equipment and discusses the methods of selection of equipment for various systems.—The Permutit Co., a division of Pfaudler Permutit Inc.

Circle No. R-560 on Reader Service Card

Water Treatment System, Complete

Bulletin AH-510. A single sheet showing construction details of the new "unitized" Hardinge Water Treatment System which contains flocculation, sedimentation and sand filtration elements in one compact system utilizing common wall construction.—The Hardinge Co., Inc.

Circle No. R-561 on Reader Service Card

Water Well Development

Bulletin 960-B covers the development of old and new sand and gravel wells by surging, acid treatment and air.—Cook Well Strainer Co.

Circle No. R-562 on Reader Service Card

Water Well Strainers

Bulletin 960-A covers the selection, specifications and installation of strainers under various conditions. It describes and illustrates various types of well strainers.—Cook Well Strainer Co.

Circle No. R-563 on Reader Service Card

Water Well Strainers for Gravel Wall Wells

Bulletin 960-A covers complete details and illustrations of Cook Heavy Type strainers that are designed especially for this type of well.—Cook Well Strainer Co.

Circle No. R-564 on Reader Service Card

Water Works Promotion

A 16 page illustrated booklet titled, "Water—Make Sure You'll Always Have Plenty," is one of the first to detail a complete plan for local support of water system improvements. It shows how responsible citizens can learn from their public officials the needs and plans of their community. —Cast Iron Pipe Research Assn.

Circle No. R-565 on Reader Service Card

Water Works Supplies

Catalog ww-60, a 56 page illustrated booklet covering pipe, tube, mechanical joint and socket fittings, couplings, sleeves, no thread fittings, repair sleeves & clamps, valves, indicator posts, valve boxes, hydrants, stops, service clamps, goosenecks, water meter yokes, melting furnaces, tools and torches available.—Grinnell Co., Inc.

Circle No. R-566 on Reader Service Card

Waste Odor Control

4-page brochure describes how typical waste odor problems may be solved. This company's odor counteractant chemicals quickly and thoroughy kill odors emanating from pumping stations, grit screen areas, digesters, trickling filters, sludge beds and lagoons.—Airkem, Inc.

Circle No. R-567 on Reader Service Card

Weir Recording Meter

Bulletin 405 describes an economical recording meter, type "LW" for use with 90° or 60° "V" Notch Weirs. Pre-engineered for standard capacities of 100,000 or 50,000 gpd and outdoor mounting. — Simplex Valve and Meter Co.

Circle No. R-568 on Reader Service Card

Well Water Systems

Bulletin 10 illustrates and discusses pumps, drilling, allied services and equipment available.—Layne & Bowler, Inc.

Circle No. R-569 on Reader Service Card

Wrenches, Pipe or Hex

Form 127 pictures the New Wheeler Combination Pipe or Hex Wrench and explains its many advantages as a conventional pipe wrench and for use on soft metal hex fittings and fittings of unusual shape. — Wheeler Mfg. Corp.

Circle No. R-570 on Reader Service Card

Wrought Iron Sewage Installations

A 30-page bulletin describes numerous applications of wrought iron pipe and plate in sewage treatment and disposal plants of leading American cities. Some unusual design features emphasize wrought iron's versatility in corrosive sewage service.—A. M. Byers Co.

Circle No. R-571 on Reader Service Card

Zeolite Water Softeners

This 20-page bulletin details the troubles caused by using hard water and the many economies effected by curing these troubles. It also contains equipment specifications, operating characteristics, and data on ion exchange resins.—The Permutit Co., a division of Pfaudler Permutit Inc.

Circle No. R-572 on Reader Service Card

Product Directory and Purchasing Guide

Water and Sewage Works Equipment and Supplies

((FOR INFORMATION ON ANY PRODUCT LISTED IN THIS DIRECTORY AND PURCHASING GUIDE FILL OUT READER SERVICE CARD.))

A

ACIDS, SULFURIC & HYDROCHLORIC
General Chemical Div., Allied Chemical Corp.

ACTIVATED CARBON
Infilco, Inc.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

AERATION EQUIPMENT
American Well Works
Infilco, Inc.
Link-Belt Co.
Pacific Flush Tank Co.
Permutit Co., The, Div. Pfaudler Permutit, Inc.
Yeomans Bros. Co.

AGITATORS
Jones, E. D., Corp.
Sveen-Pederson

AIR BLOWERS (see Blowers, Air)

AIR COMPRESSORS (see Compressors, Air)

AIR RELIEF VALVES (see Valves)

ALGAECIDES
Allis-Chalmers

ALTERNATORS, ELECTRIC
Allis-Chalmers

ALUM, LIQUID
General Chemical Div., Allied Chemical Corp.

ALUM, SULFATE OF ALUMINA
General Chemical Div., Allied Chemical Corp.

AMMONIA
General Chemical Div., Allied Chemical Corp.

ANALYZERS, WATER SYSTEMS
General Controls Co.

ASH HANDLING EQUIPMENT
Link-Belt Co.
Nichols Engineering & Research Corp.

AUTOMATIC CONTROL EQUIPMENT
B-I-F Industries, Div. of New York Air Brake Co.
Infilco, Inc.
Ludlow Rensselaer Valve Mfg. Co.
Synchro-Start Products, Inc.

B

BACKFLOW CONTROL EQUIPMENT
Ludlow Rensselaer Valve Mfg. Co.

BAR SCREENS (see Screens)

BEARINGS
Link-Belt Co.

BLOWERS, AIR
Allis-Chalmer Mfg. Co.
Hoffman Industries, Inc.
Worthington Corp.

BOXES (see Curb Boxes, Meter Boxes, Service and Valve-Boxes)

BRASS GOODS, FITTINGS, ETC.
Hays Mfg. Co.
McDonald, A. Y., Mfg. Co.
Mueller Co.

BUTTERFLY VALVES (see Valves)

C

CABLE, FLEXIBLE
Ohio Tool & Engineering Co.

CARBONATORS
Infilco, Inc.

CAR SPOTTERS
Link-Belt Co.

CATHODIC PROTECTION
Harco Corp.

CEMENTS, ACID & ALKALI PROOF
Stebbins Engineering & Mfg. Co., The

CEMENTS, REFRACTORY
Plibrico Co.

CENTRIFUGES
Permutit Co., The, Div. Pfaudler Permutit, Inc.

CHAINS, CONVEYING, ETC.
Chain Belt Co.
Link-Belt Co.

CHEMICAL CONVEYORS (see Conveying Equipment)

CHEMICAL FEEDERS
B-I-F Industries, Div. of New York Air Brake Co.
Infilco, Inc.
Permutit Co., The, Div. Pfaudler Permutit, Inc.
Wallace & Tiernan, Inc.

CHLORINATORS
B-I-F Industries, Div. of New York Air Brake Co.
Capital Controls Co., Inc.
Fischer & Porter Co.

CHLORINE, LIQUID
Columbia Southern Chemical Div., Pittsburgh Plate Glass Co.

CLAMPS, SLEEVES, BELL JOINTS
Dresser Mfg. Div., Dresser Industries, Inc.
Skinner, M. B. Co.
Smith-Blair, Inc.

CLARIFIER EQUIPMENT
American Well Works
Chain Belt Co.
Dorr-Oliver, Inc.
General Filter Co.
Hardinge Co., Inc.
Infilco, Inc.
Jones, E. D., Corp.
Link-Belt Co.
Sveen-Pederson
Walker Process Equipment Inc.
Yeomans Bros. Co.

CLEANING EQUIPMENT, MAINS
Centriline Corp.
Ohio Tool & Engineering Co.

CLEANING EQUIPMENT, SEWERS
Ohio Tool & Engineering Co.

CLEANING SERVICES, MAINS, SEWERS
American Pipe Cleaning Co.
Centriline Corp.
National Power Rodding Corp.
National Water Main Cleaning Co.

COAGULATING AIDS
General Chemical Div., Allied Chemical Corp.
Naico Chemical Co.
Permutit Co., The, Div. Pfaudler Permutit, Inc.
Tennessee Corporation

COAGULATING EQUIPMENT
Infilco, Inc.
Link-Belt Co.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

COATINGS & LININGS, BITUMINOUS
National Water Main Cleaning Co.
Stebbins Engineering & Mfg. Co., The

COATINGS & LININGS, CEMENT
Centriline Corp.
National Water Main Cleaning Co.
Stebbins Engineering & Mfg. Co., The

COATINGS & LININGS, PLASTIC
Centriline Corp.
Hauger-Beegle Assoc., Inc.
National Water Main Cleaning Co.
Stebbins Engineering & Mfg. Co., The

COATING & LININGS, OTHER
Stebbins Engineering & Mfg. Co., The

COCKS, CURB, METER, CORP, ETC.
Hays Mfg. Co.
McDonald, A. Y., Mfg. Co.
Mueller Co.

COLLECTORS, SLUDGE (see Sludge Collectors)

COMMINUTING EQUIPMENT
Infilco, Inc.
Worthington Corp.

COMPRESSORS, AIR
Allis-Chalmers Mfg. Co.
Fairbanks, Morse & Co., Compressor Div.
Worthington Corp.

CONCRETE BREAKERS
Worthington Corp.

CONCRETE MIXER
Chain Belt Co.
Worthington Corp.

CONDENSERS, STEAM
Allis-Chalmers Mfg. Co.

CONSTRUCTION EQUIPMENT
Allis-Chalmers Mfg. Co.
Chain Belt. Co.
Worthington Corp.

CONTRACTORS, WATER & SEWAGE
Roberts Filter Mfg. Co.

CONTROL PANELS
Allis-Chalmers Mfg. Co.
B-I-F Industries, Div. of New York Air Brake Co.
General Controls Co.
Permutit Co., The, Div. Pfaudler Permutit, Inc.
Synchro-Start Products, Inc.

CONTROLLERS, DENSITY, PERCENT SOLIDS
Industrial Nucleonics Corp.

CONTROLLERS, FLOW
B-I-F Industries, Div. of New York Air Brake Co.
General Controls Co.
Ludlow Rensselaer Valve Mfg. Co.
McAleer Mfg. Co.
Mueller Co.

CONTROLLERS, LEVEL
B-I-F- Industries, Div. of New York Air Brake Co.
General Controls Co.
Industrial Nucleonics Corp.
Ludlow Rensselaer Valve Mfg. Co.
McAleer Mfg. Co.

CONTROLLERS, PRESSURE
General Controls Co.
Ludlow Rensselaer Valve Mfg. Co.
McAleer Mfg. Co.
Mueller Co.

CONTROLLERS, TEMPERATURE
General Controls Co.
McAleer Mfg. Co.
Mueller Co.

CONVEYING EQUIPMENT
Chain Belt Co.
Link-Belt Co.

COPPER SULFATE
Phelps Dodge Refining Corp.

CORROSION PROTECTION (see Cathodic Protection; Coatings & Linings)

COUPLINGS, PIPE (see Joints)

COUPLINGS, SHAFT
Link-Belt Co.

COVERS, VAULT
Neenah Foundry Co.

CULVERT, PIPE (see Pipe, Culvert)

CURB BOXES
Hays Mfg. Co.
McDonald, A. Y. Mfg. Co.
Neenah Foundry Co.
Opelika Foundry Co.
Mueller Co.

D

DATA SYSTEMS
B-I-F Industries, Div. of New York Air Brake Co.

D. C. SOLENOIDS
Synchro-Start Products, Inc.

DEAERATORS
Allis-Chalmers Mfg. Co.
Permutit Co., The, Div. Paudler Permutit, Inc.
Worthington Corp.

DECHLORINATING EQUIPMENT, CHEMICALS
General Chemical Div., Allied Chemical Corp.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

DEGRITTERS
Western Machinery Co.

DE-MINERALIZATION EQUIPMENT, WATER
Allis-Chalmers
Infilco, Inc.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

DEODORIZING CHEMICALS
Airkem
Carus Chemical Co., Inc.
Pollution Control Chemicals Div., Fine Organics, Inc.

DESALINIZATION (see Chemical Feeders)

DIAPHRAGMS, PUMP
McDonald, A. Y. Mfg. Co.

DIATOMITE FILTERS (see Filters, Diatomite)

DIESEL ENGINES (see Engines, Diesel)

DIFFUSERS
American Well Works
Filtros Inc.
Link-Belt Co.
Pacific Flush Tank Co.

DIGESTER EQUIPMENT
Infilco, Inc.
Link-Belt Co.
Pacific Flush Tank Co.

DISTRIBUTORS, SEWAGE FILTER
American Well Works
Link-Belt Co.
Pacific Flush Tank Co.
Yeomans Bros. Co.

DRAINS, GUTTER, FLOOR
McDonald, A. Y., Mfg. Co.
Neenah Foundry Co.

DRIVES, CHAIN (see Chains)

DRIVES, GEAR
Johnson Gear & Mfg. Co.
Link-Belt Co.

DRIVES, V-BELT
Worthington Corp.

DRIVES, VARIABLE SPEED
Link-Belt Co.

DRYING SYSTEMS, SLUDGE
Allis-Chalmers
Combustion Engineering, Inc.
Link-Belt Co.
Nichols Engineering & Research Corp.

E

EARTH MOVING EQUIPMENT
Allis-Chalmers

EJECTORS, PNEUMATIC, STEAM
Worthington Corp.
Yeomans Bros. Co.

ELECTRIC MOTORS (see Motors)

ELECTRICAL CONTROLS (see Control Panels)

ELEVATING EQUIPMENT (see Conveying Equipment)

ENGINE-GENERATOR UNITS
Allis-Chalmers Mfg. Co.
Electric Machinery Mfg. Co.
Enterprise Div., General Metals Corp.
Fairbanks, Morse & Co., Engine Div.
White Diesel Engine Div., White Motor Co.
Worthington Corp.

ENGINES, DIESEL
Allis-Chalmers Mfg. Co.
Enterprise Div., General Metals Corp.
Fairbanks, Morse & Co., Engine Div.
White Diesel Engine Div., White Motor Co.
Worthington Corp.

ENGINES, DUAL FUEL
Allis-Chalmers Mfg. Co.
Enterprise Div., General Metals Corp.
Fairbanks, Morse & Co., Engine Div.
White Diesel Engine Div., White Motor Co.

ENGINES, GAS
White Diesel Engine Div., White Motor Co.

ENGINES, GASOLINE
Allis-Chalmers Mfg. Co.
Fairbanks, Morse & Co., Engine Div.

ENGINES, SLUDGE GAS
Climax Engine Mfg. Co., Div. of Waukesha Motor Co.
Enterprise Div., General Metals Corp.
White Diesel Engine Div., White Motor Co.

EXCAVATING EQUIPMENT (See Earth Moving Equipment)

EXHAUSTERS, AIR (See Fans; also Pumps)

EXPANSION JOINTS (see Joints, Expansion)

F

FANS, EXHAUST & VENTILATING
Worthington Corp.

FEEDERS, CHEMICALS (see Chemical Feeders)

FEEDWATER TREATMENT EQUIPMENT
Infilco, Inc.
Worthington Corp.

FERRIC CHLORIDE FEEDERS (see Chemical Feeders)

FERRIC SULFATE
Tennessee Corporation

FILTER AIDS
Permutit Co., The, Div. Pfaudler Permutit, Inc.

FILTER MEDIA
Anthracite Equipment Corp.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

FILTER PLATES & TUBES
Filtros Inc.

FILTER RATE CONTROLLERS (see Controllers, Flow)

FILTER UNDERDRAINS, SEWAGE
Texas Vitrified Pipe Co.

FILTER UNDERDRAINS, WATER
B-I-F Industries, Div. of New York Air Brake Co.
Filtros Inc.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

FILTERS, DIATOMITE
Adams, R. P. Co., Inc.
Infilco, Inc.

FILTERS, MEMBRANE
Millipore Filter Corp.

FILTERS, PRESSURE
Infilco, Inc.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

FILTERS, SAND
Infilco, Inc.
Pacific Flush Tank Co.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

FILTERS, TRICKLING
American Well Works
Natco Corp.
Pacific Flush Tank Co.

FILTERS, VACUUM
Komline-Sanderson Engineering Corp.
Nichols Engineering & Research Corp.

FILTERS, VACUUM DIATOMITE
B-I-F- Industries, Div .of New York Air Brake Co.

FITTINGS, MAINS
Dresser Mfg. Div.

FITTINGS, SERVICE
Dresser Mfg. Div.
Hays Mfg. Co.
Mueller Co.

FITTINGS, PIPE, SOLDER TYPE
Mueller Co.

FLASH MIXING EQUIPMENT (see Mixers and Mixing Equipment)

FLEXIBLE JOINTS (see Joints, Flexible)

FLOATING COVERS, DIGESTER
Graver Tank & Mfg. Co., Div. Union Tank Car Co.
Infilco, Inc.
Link-Belt Co.
Pacific Flush Tank Co.

FLOCCULATING EQUIPMENT
American Well Works
Chain Belt Co.
Infilco, Inc.
Link-Belt Co.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

FLOTATION EQUIPMENT
Chain Belt Co.
Jones, E. D., Corp.
Permutit Co., The, Div. Pfaudler Permutit, Inc.
Sveen-Pederson
Western Machinery Co.

FLOW METERS (see Meters, Flow)

FLOORING (see Gratings, Floorings)

FLOW RECORDERS (see Controllers; Gages; Recording; Instruments)

FLUORIDATION CHEMICALS
General Chemical Div., Allied Chemical Corp.

FORMS & GASKETS FOR PIPE JOINTS (see Gaskets; also Jointings)

FURNACES
Nichols Engineering & Research Corp.

G

GAGES, FLOWRATE
B-I-F Industries, Div. of New York Air Brake Co.
General Controls Co.

GAGES, LIQUID LEVEL
B-I-F Industries, Div. of New York Air Brake Co.
General Controls Co.
Industrial Nucleonics Corp.
Pacific Flush Tank Co.

GAGES, LOSS OF HEAD
B-I-F Industries, Div. of New York Air Brake Co.
General Controls Co.

GAGES, PRESSURE
General Controls Co.
Terriss—Consolidated Industries

GARBAGE GRINDERS (see Grinders)

GARBAGE & REFUSE REDUCTION EQUIPMENT
Gruendler Crusher & Pulv. Co.

GAS CONTROL EQUIPMENT
Mueller Co.
Pacific Flush Tank Co.

GAS DIFFUSERS
Infilco, Inc.

GAS ENGINES (see Engines, Gas)

GAS HOLDERS
Pacific Flush Tank Co.

GATES, SHEAR
Mueller Co.
Neenah Foundry Co.
Rodney Hunt Machine Co.

GATES, SLUICE
Allis-Chalmers Mfg. Co.
Chapman Valve Mfg. Co., The
Rodney Hunt Machine Co.

GATE VALVES (see Valves, Gate)

GEARS, SPEED REDUCING
Link-Belt Co.

GENERATOR SETS (see Engine-Generator Units)

GENERATORS, ELECTRIC
Allis-Chalmers
Electric Machinery Mfg. Co.

GOOSENECKS
Hays Mfg. Co.
McDonald, A. Y., Mfg. Co.
Mueller Co.

GRATINGS, FLOORINGS, RAILINGS
Borden Metal Products Co.
Neenah Foundry Co.
Washington Aluminum Co.

GREASE CONTROL EQUIPMENT
Jones, E. D., Corp.
Sveen-Pederson

GREEN SAND
Permutit Co., The, Div. Pfaudler Permutit, Inc.

GRINDERS, GARBAGE, SCREENINGS
American Well Works
Chain Belt Co.
Gruendler Crusher & Pulv. Co.
Nichols Engineering & Research Corp.

GRIT CHAMBERS, WASHERS
American Well Works
Chain Belt. Co.
Link-Belt Co.

GUNITE EQUIPMENT
Indiana Gunite & Construction Co., Inc.

H

HEATERS, DIGESTER
Link-Belt Co.
Pacific Flush Tank Co.

HYDRANTS
McDonald, A. Y., Mfg. Co.
M & H Valve & Fittings Co.
Mueller Co.

HYDRAULIC GATE VALVES (see Valves, Hydraulic)

HYPO-CLORINATORS
B-I-F Industries, Div. of New York Air Brake Co.
Chem/Tech International

I

INCINERATOR EQUIPMENT
Combustion Engineering, Inc.
Morse Boulger, Inc.
Nichols Engineering & Research Corp.

INCINERATORS, SLUDGE & GARBAGE
Combustion Engineering, Inc.
Morse Boulger, Inc.
Nichols Engineering & Research Corp.
Pilbrico. Co.

INDICATORS, LARGE DIAL
B-I-F Industries, Div. of New York Air Brake Co.

INDUSTRIAL WASTE COAGULANT
Tennessee Corporation

INSERTING EQUIPMENT, MACHINES
Mueller Co.

INSERTION VALVES & FITTINGS (see Valves; Fittings; also Jointings)

INSTRUMENTS, RECORDING (see Recording Instruments)

INTAKE SCREENS (see Screens)

IRON REMOVAL CHEMICALS
Carus Chemical Co., Inc.

IRON REMOVAL EQUIPMENT
Allis-Chalmers
Infilco, Inc.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

IRON SULFATE (see Ferric Sulfate)

J

JOINTS, EXPANSION, PIPE
Dresser Mfg. Div.
Smith-Blair, Inc.

JOINTS, FLEXIBLE, PIPE
Dresser Mfg. Div., Dresser Industries, Inc.
Hamilton Kent Mfg. Co.
Smith-Blair, Inc.
United States Concrete Pipe Co.

JOINTS, MECHANICAL FLEXIBLE
Dresser Mfg. Div., Dresser Industries, Inc.

L

LABORATORY EQUIPMENT
Phipps & Bird, Inc.

LEAK DETECTORS
National Power Rodding Corp.

LIFT STATIONS
American Well Works
Blackburn-Smith Mfg. Co., Inc.
Smith & Loveless, Div. Union Tank Car Co.
Tex-Vit Mfg. Co.

LINER PLATES
United States Concrete Pipe Co.

LINING, PIPE, TANKS (see Coatings and Linings)

LIQUID CHLORINE (see Chlorine, Liquid)

LOCATORS, PIPE & VALVE
Gardiner Electronics Co.

M

MANGANESE REMOVAL CHEMICALS
Carus Chemical Co., Inc.

MANHOLE FRAMES, COVERS
Ludlow Rensselaer Valve Mfg. Co.
Neenah Foundry Co.
Opelika Foundry Co.

MANOMETERS
General Controls Co.

METER BOXES
Ford Meter Box Co., Inc. The
Mueller Co.
Neenah Foundry Co.
Opelika Foundry Co.

METER COUPLINGS, YOKES
Ford Meter Box Co., Inc., The
Hays Mfg. Co.
Mueller Co.
Smith-Blair, Inc.

METER REPAIR PARTS
Neptune Meter Co.

METER TESTING EQUIPMENT
Neptune Meter Co.

METERS, FLOW (see Gages)

METERS, VENTURI
B-I-F Industries, Div. of New York Air Brake Co.
General Controls Co.
Infilco, Inc.

METERS, WATER, COMPOUND
Neptune Meter Co.

METERS, WATER, COUPLING
Neptune Meter Co.

METERS, WATER, CURRENT
Neptune Meter Co.

METERS, WATER, DISPLACEMENT
Neptune Meter Co.

METERS, WATER, FIRE SERVICE
Neptune Meter Co.

METERS, WATER, RECORDING
Neptune Meter Co.

MIXERS & MIXING EQUIPMENT
American Well Works
Gruendler Crusher & Pulv. Co.
Infilco, Inc.
Link-Belt Co.
Western Machinery Co.

MOTORS, ELECTRIC
Allis-Chalmers Mfg. Co.
Electric Machinery Mfg. Co.
Fairbanks, Morse & Co., Motors Div.
Smith, A. O., Corp.

MOTORS, GEAR
Link-Belt Co.

MOTORS, OTHER (see Engines)

N

NOZZLES, FLOW
B-I-F Industries, Div. of New York Air Brake Co.

NOZZLES, SPRAY
Link-Belt Co.
Worthington Corp.

O

ODOR CONTROLLERS (see Taste and Odor Removers)

OPERATING TABLES, FILTER
B-I-F Industries, Div. of New York Air Brake Co.
Infilco, Inc.

ORIFICES
General Controls Co.
Pacific Flush Tank Co.

ORIFICES, AIR DIFFUSERS
Link-Belt Co.

P

PACKAGE TREATMENT EQUIPMENT
American Well Works
Chain Belt. Co.
Chicago Pump, Hydrodynamics Div., FMC Corp.
Infilco, Inc.
Link-Belt Co.
Nichols Engineering & Research Corp.
Yeomans Bros. Co.

PACKAGED WATER TREATMENT PLANTS
Met-Pro, Inc.

PACKING, PUMPS & VALVES
Newage Industries Inc.

PAINT, SPECIAL PURPOSE
Hauger-Beegle Assoc., Inc.

PENSTOCKS
Graver Tank & Mfg. Co., Div. Union Tank Car Co.

PHOSPHATES
General Chemical Div., Allied Chemical Corp.

PHOSPHORIC ACID, NUTRIENT FEED
General Chemical Div., Allied Chemical Corp.

PIPE, AGRICULTURAL
American Concrete Pipe Assn.

PIPE, ASBESTOS-CEMENT
Indussa Corp.
Johns-Manville Corp.
Keasbey & Mattison Co.

PIPE, CAST IRON
American Cast Iron Pipe Co.
United States Pipe & Foundry Co.

PIPE, CLAY
Texas Vitrified Pipe Co.
United States Concrete Pipe Co.

PIPE, CONCRETE
American Concrete Pipe Assn.
American Concrete Pressure Pipe Assn.
United States Concrete Pipe Co.

PIPE, CULVERT
American Concrete Pipe Assn.
United States Concrete Pipe Co.

PIPE, DRAINAGE
American Concrete Pipe Assn.

PIPE, LINED
United States Concrete Pipe Co.

PIPE, PLASTIC
Keasbey & Mattison Co.

PIPE, PRESSURE
American Concrete Pressure Pipe Assn.

PIPE, SEWER
American Concrete Pipe Assn.
Keasbey & Mattison Co.
United States Concrete Pipe Co.

PIPE, STEEL
Bethlehem Steel Co., Inc.

PIPE, CEMENT LINING OF (see Coatings and Linings)

PIPE CLEANING (see Cleaning Services)

PIPE COATINGS & LININGS (see Coatings and Linings)

PIPE COUPLINGS & FITTINGS (see Joints)

PIPE CUTTING MACHINES
Wachs, E. H., Co.
Wheeler Mfg. Corp.

PIPE FINDERS (see Locators)

PIPE FITTINGS (see Fittings)

PIPE HANDLING EQUIPMENT
Cleveland Trencher Co., The

PIPE INSPECTION EQUIPMENT
Centriline Corp.
National Power Rodding Corp.

PIPE INSPECTION EQUIPMENT—T.V. Inspection
American Pipe Cleaning Co.

PIPE JOINT PACKING (see Packing)

PIPE LAYING EQUIPMENT (see Trenchers)

PIPE LEAK DETECTORS (see Leak Detectors)

PIPE TAPPING MACHINES (see Tapping, Drilling Equipment)

PILOT TUBES
General Controls Co.

POTASSIUM PERMANGANATE
Carus Chemical Co., Inc.

PRESSURE REGULATORS (see Controllers)

PROPORTIONING EQUIPMENT (see Chemical Feeders)

PROTECTIVE COATINGS (see Coatings; also Paints)

PIPE PRIMERS

PUMPING CONTROLS (see Controllers)

PUMPS, ACID-HANDLING
Allis-Chalmers Mfg. Co.
Gorman-Rupp Co.
Goulds Pumps, Inc.
Worthington Corp.

PUMPS, AIRLIFT
American Well Works

PUMPS, BOILER FEED
Allis-Chalmers Mfg. Co.
Fairbanks, Morse & Co., Pump Div.
Goulds Pumps, Inc.
Worthington Corp.

PUMPS, CELLAR DRAINER (see Pumps, Sump)

PUMPS, CENTRIFUGAL
Allis-Chalmers Mfg. Co.
American Well Works
Fairbanks, Morse & Co., Pump Div.
Gorman-Rupp Co.
Goulds Pumps, Inc.
McDonald, A. Y., Mfg. Co.
McGowan Pumps
Ohio Tool & Engineering Co.
Western Machinery Co.
Worthington Corp.
Yeomans Bros. Co.

PUMPS, CHEMICAL FEED
B-I-F Industries, Div. of New York Air Brake Co.
Gorman-Rupp Co.
Worthington Corp.

PUMPS, DEEP WELL
American Well Works
Fairbanks, Morse & Co., Pump Div.
Layne & Bowler Pump Co.
McDonald, A. Y., Mfg. Co.
Worthington Corp.

PUMPS, DIAPHRAGM
Gorman-Rupp Co.
McGowan Pumps

PUMPS, DRAINAGE (see Pumps, Sewage and Drainage)

PUMPS, HYDRAULIC BOOSTER
Gorman-Rupp Co.
Ludlow Rensselaer Valve Mfg. Co.
Worthington Corp.

PUMPS, PORTABLE
Chain Belt. Co.
Fairbanks, Morse & Co., Pump Div.
Gorman-Rupp Co.
Goulds Pumps, Inc.
McGowan Pumps
Ohio Tool & Engineering Co.
Worthington Corp.

PUMPS, ROTARY
Fairbanks, Morse & Co., Pump Div.
McDonald, A. Y., Mfg. Co.
Worthington Corp.

PUMPS, SELF-PRIMING
Fairbanks, Morse & Co., Pump Div.
Gorman-Rupp Co.
McDonald, A. Y. Mfg. Co.
McGowan Pumps
Ohio Tool & Engineering Co.
Worthington Corp.

PUMPS, SEWAGE & DRAINAGE
Allis-Chalmers Mfg. Co.
American Well Works
Fairbanks, Morse & Co., Pump Div.
Gorman-Rupp Co.
McDonald, A. Y. Mfg. Co.
McGowan Pumps
Marlow Pumps
Western Machinery Co.
Worthington Corp.
Yeomans Bros. Co.

PUMPS, SLUDGE
Allis-Chalmers Mfg. Co.
American Well Works
Gorman-Rupp Co.
McGowan Pumps
Western Machinery Co.
Worthington Corp.

PUMPS, SUBMERSIBLE
Fairbanks, Morse & Co., Pump Div.
Gorman-Rupp Co.
Goulds Pumps, Inc.
Layne & Bowler Pump Co.
McDonald, A. Y. Mfg. Co.
Western Machinery Co.
Worthington Corp.

PUMPS, SUMP
Fairbanks, Morse & Co., Pump Div.
Gorman-Rupp Co.
Goulds Pumps, Inc.
Layne & Bowler Pump Co.
McDonald, A. Y. Mfg. Co.
Worthington Corp.
Yeomans Bros. Co.

PUMPS, TURBINE
Allis-Chalmers Mfg. Co.
Fairbanks, Morse & Co., Pump Div.
Layne & Bowler Pump Co.
Worthington Corp.

PUMPS, VACUUM
Allis-Chalmers Mfg. Co.
Worthington Corp.

R

RAILINGS (see Gratings, Floorings, Railings)

RATE OF FLOW CONTROLLERS (See Controllers)

RATE OF FLOW GAGES (See Gages)

RECARBONATORS (See Carbonators)

RECORDING INSTRUMENTS
B-I-F Industries, Div. of New York Air Brake Co.
Foxboro Co.
General Controls Co.

REFRACTORIES
Plibrico Co.

REGULATORS, PRESSURE (see Controllers)

RESERVOIRS, STEEL (see Tanks)

RUST PREVENTION, WATER TREATMENT
American Pipe Cleaning Co.

S

SADDLES, PIPE
Mueller Co.
Opelika Foundry Co.
Skinner, M. B., Co.
Smith-Blair, Inc.

SALT WATER CONVERSION EQUIP.
Chicago Bridge & Iron Co.
Fairbanks, Morse & Co., Water Div.

SAND EXPANSION INDICATORS
B-I-F Industries, Div. of New York Air Brake Co.

SAND TREATING EQUIPMENT
Western Machinery Co.

SCALE (CHEMICAL) REMOVAL
American Pipe Cleaning Co.
General Chemical Div., Allied Chemical Corp.
Worthington Corp.

SCALES, CONVEYOR
B-I-F- Industries, Div. of New York Air Brake Co.
Fairbanks, Morse & Co., Scale Div.
Merrick Scale Mfg. Co.

SCREENINGS & COMMINUTING (see Comminuting Equipment)

SCREENING GRINDERS (see Grinders)

SCREENS, INTAKE
Chain Belt. Co.
Link-Belt Co.
Rodney Hunt Machine Co.

SCREENS, SEWAGE
American Well Works
Chain Belt Co.
Link-Belt Co.

SCREENS, VIBRATING
Allis-Chalmers
Link-Belt Co.

SCREENS, WATER WELL
Cook Well Strainer Co.

SCUM REMOVERS
Chain Belt Co.
Link-Belt Co.
Pacific Flush Tank Co.

SEDIMENTATION EQUIPMENT (see Clarifier Equipment)

SEPARATORS, OIL REMOVAL
Chain Belt Co.
Infilco, Inc.

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McDonald, A. Y., Mfg. Co.
Mueller Co.
Opelika Foundry Co.

SEWAGE COAGULANT
Tennessee Corporation

SEWAGE EJECTORS (see Ejectors)

SEWAGE SAMPLERS
Link-Belt Co.
Phipps & Bird, Inc.

SEWAGE SLUDGE DRYERS (see Drying Systems)

SEWAGE SLUDGE INCINERATORS (see Incinerators)

SEWER CLEANING (see Cleaning)

SIPHONS, SEWAGE DOSING
Pacific Flush Tank Co.

SLEEVES, PIPE REPAIR
Dresser Mfg. Div.
Mueller Co.
Smith-Blair, Inc.

SLEEVES, TAPPING, VALVE
Dresser Mfg. Div.
Mueller Co.

SLUDGE COLLECTORS
American Well Works
Chain Belt. Co.
Link-Belt Co.
Yeomans Bros. Co.

SLUDGE CONDITIONING
Tennessee Corporation

SLUDGE DRYING (GLASS ENCLOSURES)
Lord & Burnham Co.

SLUDGE REMOVING EQUIPMENT
American Well Works
Chain Belt. Co.
Link-Belt Co.

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Nalco Chemical Co.

SODIUM SILICATE
General Chemical Div., Allied Chemical Corp.
Philadelphia Quartz Co.

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Link-Belt Co.

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Chicago Bridge & Iron Co.
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STORAGE TANKS (see Tanks)

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Kinney, S. P., Engineers, Inc.
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B-I-F- Industries, Div. of New York Air Brake Co.
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Voidale, Inc.

SWITCHES, SPEED SENSITIVE
Synchro-Start Products, Inc.

T

TANK PAINTING
Neumann Company Contractors, Inc.

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Graver Tank & Mfg. Co., Div. Union Tank Car Co.

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Chicago Bridge & Iron Co.
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Preload Co., Inc., The

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Chicago Bridge & Iron Co.
General American Transportation Corp.
Graver Tank & Mfg. Co., Div. Union Tank Car Co.
McDonald, A. Y., Mfg. Co.

TAPPING, DRILLING EQUIPMENT
Hays Mfg. Co.
Mueller Co.

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Carus Chemical Co., Inc.
Industrial Chemical Sales Div.
Permutit Co., The, Div. Pfaudler Permutit, Inc.

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B-I-F- Industries, Div. of New York Air Brake Co.

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American Pipe Cleaning Co.

TRANSFORMERS
Allis-Chalmers
General Controls Co.

TRANSMISSION MACHINERY, POWER
Link-Belt Co.

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American Well Works
Infilco, Inc.
Permutit Co., The, Div. Pfaudler Permutit, Inc.
Yeomans Bros. Co.

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Cleveland Trencher Co., The

TRICKLING FILTERS (see Filters, Trickling)

TURBINES
Allis-Chalmers Mfg. Co.
Worthington Corp.

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VACUUM FILTERS (see Filters, Vacuum)

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Mueller Co.
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Chapman Valve Mfg. Co., The
General Controls Co.
Rodney Hunt Machine Co.
Wachs, E. H., Co.

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Chapman Valve Mfg. Co., The
General Controls Co.
Ludlow Rensselaer Valve Mfg. Co.
McDonald, A. Y., Mfg. Co.
Mueller Co.
Multiplex Mfg. Co.

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Chapman Valve Mfg. Co., The
General Controls Co.
Golden-Anderson Valve Spec. Co.
Ludlow Rensselaer Valve Mfg. Co.
Pratt, Henry, Co.

VALVES, BALL
Allis-Chalmers Mfg. Co.
General Controls Co.
McAleer Mfg. Co.
McDonald, A. Y., Mfg. Co.
Pratt, Henry, Co.

VALVES, BUTTERFLY
Allis-Chalmers Mfg. Co.
B-I-F Industries, Div. of New York Air Brake Co.
Chapman Valve Mfg. Co., The
General Controls Co.
Kinney, S. P., Engineers, Inc.
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Chapman Valve Mfg. Co., The
General Controls Co.
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Ludlow Rensselaer Valve Mfg. Co.
McDonald, A. Y., Mfg. Co.
M & H Valve & Fittings Co.
Mueller Co.

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Allis-Chalmers Mfg. Co.
Chapman Valve Mfg. Co., The
General Controls Co.
Golden-Anderson Valve Spec. Co.
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General Controls Co.
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M & H Valve & Fittings Co.
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Allis-Chalmers Mfg. Co.
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Chapman Valve Mfg. Co., The
General Controls Co.
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General Controls Co.
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Allis-Chalmers Mfg. Co.
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General Controls Co.
McDonald, A. Y., Mfg. Co.
Mueller Co.

VALVES, GATE
Chapman Valve Mfg. Co., The
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M & H Valve & Fittings Co.
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Chapman Valve Mfg. Co., The
General Controls Co.
M & H Valve & Fittings Co.
Mueller Co.
Rodney Hunt Machine Co.

VALVES, PLUG
De Zurik Corp.
General Controls Co.
Hays Mfg. Co.
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VALVES, PNEUMATICALLY OPERATED
Allis-Chalmers Mfg. Co.
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General Controls Co.
McAleer Mfg. Co.
M & H Valve & Fittings Co.
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Golden-Anderson Valve Spec. Co.
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W

WATER SUPPLIES, SURFACE & UNDERGROUND
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Z

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Motor Div., Freeport, Ill.
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Industrial Chemical Sales Div., 230 Park Ave., New York, N. Y.
Industrial Nucleonics Corp., 650 Ackerman Rd., Columbus 2, Ohio
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McGowan Pumps, Div. of Leyman Mfg. Corp., 10956 Kenwood Rd., Cincinnati 42, Ohio

M & H Valve & Fittings Co., Anniston, Ala.
Marlow Pumps, Div. of Bell & Gossett Co., P. O. Box 200, Midland Park, N. J.
Merrick Scale Mfg. Co., 180 Autumn St., Passaic, N. J.
Met-Pro, Inc., 5th St. & Mitchell Ave., Lansdale, Pa.
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Morse Boulger, Inc., 80 Fifth Ave., New York, N. Y.
Mueller Co., 512 Cerro Gordo, Decatur 8, Ill.
Multiplex Mfg. Co., 600 Fowler Ave., Berwick, Pa.

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Natco Corp., 327 - Fifth Ave., Pittsburgh 22, Pa.
National Chemsearch Corp., P. O. Box 10087, Dallas 7, Tex.
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Newage Industries, Inc., 222 York Rd., Jenkintown 48, Pa.
Nichols Engineering & Research Corp., 80 Pine St., New York 5, N. Y.

Ohio Tool & Engineering Co., 128 N. Spring St., Springfield, Ohio
Opelika Foundry Co., Opelika, Ala.

Pacific Flush Tank Co., 4141 Ravenswood Ave., Chicago 13, Ill.
Permutit Co., Div. Pfaudler Permutit, Inc., 50 W. 44th St., New York, N. Y.
Phelps Dodge Refining Corp., 300 Park Ave., New York, N. Y.
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Pratt, Henry, Co., 319 W. Van Buren St., Chicago 7, Ill.
Preload Co., Inc., The, 355 Lexington Ave., New York 17, N. Y.
Ranney, Inc., 841 Alton Ave., Columbus 19, Ohio
Roberts Filter Mfg. Co., 640 Columbia Ave., Darby, Pa.
Rodney Hunt Machine Co., 84 Lake St., Orange, Mass.

Skinner, M. B., Co., 3502 W. Sample St., South Bend, Ind.

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Scranton Publishing Company, Inc.

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